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PRACTICAL TREATISE ON

# METALLURGY.

A

# PRACTICAL TREATISE

ON

# METALLURGY,

ADAPTED FROM THE LAST GERMAN EDITION

OF

PROFESSOR KERL'S METALLURGY,

BY

*WILLIAM CROOKES, F.R.S., &c.,*

AND

*ERNST RÖHRIG, Ph.D., M.E.*

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IN THREE VOLUMES—VOL. III.

STEEL, FUEL, SUPPLEMENT.

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# PREFACE.

THIS forms the third and concluding volume of a work undertaken to supply the want long felt in England of a complete and Practical Treatise on Metallurgy. Owing to the complexity and vastness of the subject, and to the continual development of new processes and inventions, the task of the authors has proved by no means easy, but they trust that they have succeeded in producing, in a compendious and somewhat complete form, a work of practical value to the Metallurgist.

Although this work is much ampler than was originally intended, it has been found necessary to give many processes in as condensed a form as possible, and to omit details which were either unnecessary to the full elucidation of the subject, or which would at once be suggested to the practical mind.

While the authors have taken the admirable treatise of Professor Kerl as the groundwork of their labours, they have given much practical information and many useful processes which are not to be found in Kerl; for as his first volume was published in 1861, the second in 1863, the third in 1864, and the last in 1865, it is evident that a mere translation of this standard work would not, at the present time, constitute anything like a complete practical treatise. An instance of this amplification is shown in the fact

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that our treatment of steel comprises twenty sheets, while, in comparison to the size of page and type, Kerl devotes but twelve, and Percy (published in 1864) about ten sheets to this subject.

Our concluding volume contains, in addition to the chapter on Steel, exhaustive chapters on Fuel, and the Materials for the Construction of Furnaces. Moreover, to bring the work to the level of the actual state of science and practical experience, we have availed ourselves of articles and reports on improved processes from some of the English and Foreign Journals, which we give in the form of a supplement. At the conclusion will be found a report of the latest experiments on Siemens's highly valuable processes for producing steel. A glossary of technical terms and tables of weights and measures are also added.

LONDON, *November*, 1869.

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# A PRACTICAL
# TREATISE ON METALLURGY.

## CHAPTER I.

## STEEL.

**Steel** differs from pig and wrought-iron in its proportion of carbon (1·4 or 1·5 per cent); it differs from pig-iron in its property of welding, and from wrought-iron in its fusibility; its melting point is about 1850° C., whilst the melting point of pig-iron is between 1400° and 1600° C. Steel is furthermore characterised by its softness at a glowing heat, and it becomes hard upon sudden cooling. These properties are modified according to the proportion of carbon, the presence or absence of certain foreign admixtures, the uniformity of its mechanical treatment, the method employed for its production, and finally, to other circumstances which are not yet well understood.

The following are the principal methods of making steel:—

### A. Steel direct from the Ores.

Formerly, steel was occasionally produced by the Catalan forge (vol. ii., p. 697), and also in crucibles.

Gurlt* proposes to treat rich pure iron ores in cupola furnaces by means of carbonising and reducing gases, and to melt the resulting product in a gas reverberatory furnace; but this method has not proved successful* when carried out on a large scale.

---

* Gurlt, die Roheisenerzeugung mittelst Gas: Freiberg, 1857. B. u. h. Ztg., 1861, p. 243.

By Chenot's† method rich pure iron ores are reduced in cupola furnaces by interstratified layers of charcoal; the resulting spongy products, containing various amounts of carbon, are sorted and ground in mills, and the mass is pressed into cylinders and melted in crucibles, sometimes, together with coal, and a purifying and scorifying flux of manganese. This method has been tried in Belgium without economical success, and it does not permit the production of cast-steel containing a fixed proportion of carbon.

Liebermeister‡ has proposed to produce steel direct in the iron blast furnace by interrupting the carbonisation at the proper moment, but this seems to be practically impossible.

The newest and most promising way of producing steel direct from the ores is Mr. Siemens's method with the regenerative gas furnace, and we therefore propose later on to describe it *in extenso*.

## B. Steel from Pig-Iron.

Steel may be produced from pig-iron—

1. **By Oxidising part of its Carbon.**—This oxidation may be performed at a *glowing red heat* and at a *melting heat*. On exposing suitable pig to a continued glowing heat with an admission of atmospheric air (Tunner's,‖ Weber's,§ and Lohmann's¶ methods), the resulting steel will be cheap but variable in its properties. We may here also mention the method introduced by Herrzeel** and Paulis,†† in which it is proposed to heat pig-iron in contact with steam, and Eaton's‡‡ method of heating pig-iron together with carbonate of soda.

---

* Berggeist, 1859, No. 56. B. u. h. Ztg., 1860, p. 27.

† B. u. h. Ztg., 1856, p. 104; 1857, p. 181; 1859, p. 225; 1860, p. 7.

‡ Ibid., 1860, pp. 137, 243, 252, 272.

‖ Leob., Jahrb., 1852, ii., 184; 1857, vi., 99.

§ Oesterr. Ztschr., 1856, No. 42.

¶ Leob., Jahrb., 1852, ii., 184.

** B. u. h. Ztg., 1861, pp. 79, 456.

†† Ibid., 1862, p. 344.

‡‡ Ibid., 1861, p. 328.

The oxidation of the carbon in the fused pig-iron may be effected by the application of blast (the production of natural steel in open fires, and Bessemer's process), or of air draught which is employed in the production of puddle steel in reverberatory furnaces. Steam is seldom employed, in which case (Sabatier's* method) the oxidation of the carbon takes place chiefly through the formed oxidised iron. When producing natural and puddle steel special fuel is employed for melting down the pig-iron and for keeping up the fused state during the conversion process; whilst in Bessemer's process the required temperature is sustained by conducting blast into the fused metal, thus causing an oxidation of iron and carbon.

The oxidation of the carbon in the fused pig-iron may be effected also by an addition of oxidising substances, such as pure rich iron ores, &c. The most important is Heaton's process, in which nitrate of soda is used as the oxidising agent, and which, therefore, we shall also describe in detail later on.

Uchatius† has produced a steel adapted for various purposes by melting in crucibles granulated pig-iron with roasted magnetic or spathic iron ore, and a small quantity of oxide of manganese. By varying the proportions of metal and ore, and especially by the addition of a certain quantity of malleable scrap iron, a softer or milder steel may be obtained. This method is adopted at Wikmannshyttan‡ in Dalekarlien, where pig-iron and rich magnetic iron ore are employed. Tunner doubts the value of this method, as the result is uncertain, and also as the crucibles are more wasted or corroded than in Chenot's method.

Obuchow produces cast-steel by melting pig-iron with magnetic iron ore, titaniferous iron sand, malleable scrap iron, arsenious acid, saltpetre, and clay, or by fusing pig-iron with an addition of magnetic iron ore and arsenious acid.

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* Oesterr. *Ztschr.*, 1863, No. 41.

† Leob., Jahrb., 1857, vi., 85, 255; 1859, viii., 154; 1862, xii., 70.

‡ Tunner's Jahrb., 1842, p. 211; 1853, iii., 309; 1857, vi., 106, 255; 1858, viii., 157. Leob., Jahrb., 1863, xii., 71.

A more uniform production may be obtained by replacing the iron ore by finely divided heated pig-iron, and fusing it with finely divided pig-iron which has not been heated, and with an addition of brown stone.

2. **By Fusing Pig-Iron in Admixture with Wrought-Iron.**—This principle has been advocated by Karsten. These methods yield a more uniform product than the methods nvented by Chenot and Uchatius, supposing that suitable raw materials have been applied in both cases. We may here mention Obersteiner's method, which is adopted at Gefle in Sweden, &c., and which consists of a fusion of pig with wrought-iron, and Cowper's method,* consisting of a fusion of pig-iron with wrought-iron and with an addition of oxide of iron and ferro-cyanide of potassium. Price and Nicholson's method consists in melting malleable iron with refined metal.

Mr. Siemens has applied his regenerative gas furnaces to the manufacture of steel from a mixture of cast- and wrought-iron on the open bed of the furnace; this (known as Siemens-Martin's process) undoubtedly is the cheapest method and allows the production of large masses.

### C. Steel from Wrought-Iron by Carbonisation.

This process may be performed either at the temperature of fusion or below the melting point.

In the latter case the bar iron is exposed to the action of solid or gaseous carbonaceous matter, which operation is termed cementation; soft puddle steel is sometimes also cemented to render it richer in carbon and harder if the steel is intended for the manufacture of rails, &c.

Various methods may be employed. The methods of producing the Indian cast-steel or wootz, the real and imitation Damascus-steel, &c., may be mentioned. Wootz is made from malleable iron cut into small pieces, which are charged in quantities of 1 lb. weight in clay crucibles with about 10 per cent of dried wood. Mushet melts wrought-iron in admixture with coal and manganese. Farrar† used an admixture of sal-ammoniac, ferro-cyanide of potassium, and manganese (method of the Damascus Steel and Iron Company of New York); Heath* uses carburet of manganese.

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* B. u. h. Ztg., 1862, p. 255.
† Ibid., 1860, p. 152.

Howell's homogeneous† metal is the softest and most tenacious kind of cast-steel; it is poorest in carbon, and stands between hard cast-steel and soft iron, as fine-grained wrought-iron stands between puddled steel and soft iron. Homogeneous metal is most frequently produced by melting very pure malleable iron with 1-140th or 1-150th part of charcoal powder; it is also produced by melting pure malleable iron in small pieces with about 50 per cent in weight of scraps of cast-steel, or by melting wrought-iron with an addition of spiegeleisen; the homogeneous metal sometimes results from the Bessemer process. In the form of plates and applied to coating vessels it resists the action of sea water better than iron plates, and is also employed for the manufacture of rails, tubes, &c.

Verdie terms half-steel (*produit mixte*) a product fit for rails; the inside consists of wrought-iron and the outside is coated with cast-steel.

**Classification of Steel according to the Treatment it Undergoes.**—Steel produced by any of these methods is more or less uniform, and is rendered homogeneous either by the operation of fusion, when it is termed *cast-steel*, or by a repeated welding and forging or rolling, in which case the product will be called *shear-steel*. The term cast-steel is also now and then applied to the inferior sorts of steel obtained by melting pig with malleable iron or with oxidising agents, &c. Cast- and shear-steel may be equal in tenacity and hardness supposing both to be produced from good pig-iron; on the other hand, a more homogeneous product results from melting than from welding and forging, if an inferior pig-iron has been employed in its production. An improvement of the cast-steel is attempted by the addition of certain substances, thus producing, according to the nature of the addition, platinum steel, silver steel, tungsten steel, &c. Steel which shows a pattern upon etching a polished section with acids, is called damasked steel.

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* Mining Journal, 1853, No. 913.

† Berggeist, 1858, pp. 163, 412. Dingl., Bd. 151, p. 199. B. u. h. Ztg., 1859, p. 303; 1861, p. 406; 1862, p. 411; 1863, p. 167. Polyt. Centr., 1862, p. 580. Leob., Jahrb., 1863, p. 62.

The additions given to the steel either do not act at all, or only in such a manner as to remove injurious substances, such as sulphur, silicon, &c., with which they combine and become scorified; this is especially the case with manganese (Heath's patent); the additions seldom enter into the steel.

**Classification of Steel according to its Applications.**—Steel intended for the manufacture of tools is produced from the best kinds of raw or cement steel, which may be refined either by fusion or by welding and forging. Steel requiring a certain hardness combined with great tenacity for cutters, &c., is produced from welded cement steel produced from Swedish iron, in preference to cast-steel which is employed in the manufacture of objects of less importance. In the manufacture of tools it is very necessary always to employ the same quality of steel, which explains the preference given to the approved modes of production though they are more expensive. This is the reason why in England Swedish iron is still employed for the production of the best kinds of cast-steel; the cemented bars when broken into pieces are carefully sorted and fused as quickly as possible in clay crucibles, but not in plumbago crucibles. In Styria the shear-steel produced from raw steel is also more expensive than cast-steel, it is said to possess more tenacity than cast-steel and equal hardness.

At present the puddle steel produced from good charcoal pig-iron has in many cases entered into competition with the raw and cement steel, especially when the steel is intended for the manufacture of tools.

As these sorts of steel are worked into the most various small objects, and are also drawn out into very thin dimensions, thus increasing their value very considerably, the application of a superior quality containing a larger amount of carbon is required, otherwise the repeated heatings required will extract too much of the carbon and render the steel too soft.

Cast-steel is often employed instead of iron for large castings, when it must be cheap, only slightly hard, homogeneous, and ductile, so as to allow an easy treatment. These kinds of steel are not worked into smaller objects, and the castings are usually finished in the steel melting works. Puddled steel is usually employed as the material for this kind of cast-steel; also steel produced from melting pig-iron with malleable iron, and steel produced from pig-iron with oxidising agents, especially Bessemer's steel, are largely employed. Cast-steel will always be superior in quality if produced from superior raw material of constant composition.

In most cases the somewhat more expensive puddled steel is preferred to Obersteiner's steel, and almost always before Uchatius's steel, as it yields cast-steel of greater homogeneousness. Bessemer steel, however, is preferable to the puddled steel for the production of large masses, as being more homogeneous, cheaper, more quickly produced, and requiring no re-melting in crucibles. Siemens's steel and Heaton's steel are likely to enter into competition with Bessemer's steel.

Petretto endeavoured to replace the cast-steel for large objects by forming the raw steel into large piles, which were then heated in reverberatory furnaces and forged under a steam hammer; however, a certain uniformity and the required homogeneousness of the large masses are better secured by fusion than by welding and forging.

Cast-steel is employed for the manufacture of railway wheels and axles, bevelled wheels, bells (bells of cast-steel manufactured in Bochum are from 18 to 102 inches in diameter and weigh from 90 to 156,000 lbs.), guns, &c.

There are very few published works on the manufacture of steel; the following treatises are those most worthy of mention:—

DAMEMME, practisches Handbuch der Stahlbereitung; deutsch von HARTMANN, 1839.

OVERMANN, die Bereitung und Verarbeitung des Stahls; deutsch von HARTMANN, 2, Auflage, 1856.

GRUNER et LAN, état présent de la Métallurgie du fer en Angleterre. Paris: 1862, page 711.

JULLIEN, Handbuch der Eisenhüttenkunde, deutsch von HARTMANN, 1861, p. 271.

TUNNER'S Abhandlungen im LEOBEN, Jahrbuch.
SCHAFHAUTL'S Artikel über Stahl, in Bd. xv. von PRECHTL'S technologischer Encyklopädie.
LANDRIN, Traité de l'acier. Paris: 1859.
DESSOYE, Etudes théoretiques, &c. Paris: 1859.

## Properties of Steel.

**Colour.**—Steel is whitish grey, or white and dull, with a silky fracture.

**Texture.**—The texture of steel is fine-grained, the grains being of an indefinite jagged shape, and somewhat lighter and finer in tempered steel than in soft steel. Tungsten steel shows a perfectly conchoidal fracture on which the grain is so fine as to be scarcely perceptible. Natural steel in the original balls, and cement steel after cementation, as well as cast-steel immediately after being cast, shows a coarse non-uniform appearance, and has but little tenacity; but the grain will become finer if the steel is drawn out at suitable temperatures to very small dimensions, and if a very high temperature has been employed in its tempering. Slowly cooled steel maintains its original texture, and hardened steel retains it if re-heated and slowly cooled. This circumstance must be taken into consideration when judging the quality of steel from the appearance of the fracture, as steel is usually considered to be of superior quality if its grain is very fine. The appearance of the fracture may prove the uniformity of steel, but does not indicate its other properties, hardness, tenacity, &c. These qualities depend on the quality and quantity of the foreign admixtures contained in the steel, and can only be determined by direct trials and tests.

Upon hardening, steel loses its crystalline grain more entirely the more perfect and the more homogeneous the steel is before hardening; therefore cast-steel undergoes a greater change than all other kinds of steel. When suitably hardened, the grain of the steel disappears almost entirely, and the steel then attains a compact fracture, even or slightly conchoidal. The smaller the grain the less lustre the steel shows, and the lighter is its colour.

A coarse light grain generally indicates an approach to the nature of wrought-iron or of a soft steel poor in carbon, and a fracture showing a mixture of more or less fine grains, partly lustrous and partly dull, proves that the steel is not homogeneous. Light, bright, and coarse grains indicate that the steel is intermixed with iron; steel sometimes contains even tough veins of iron.

The following valuable consideration on the texture of Bessemer and other steel are extracted from the "Practical Mechanics Journal" of November 1, 1865, page 226:—

"There is one grand result obtained both in steel and wrought-iron making by the puddling process which as yet has not been achieved by the Bessemer process—*the production of fibre*, upon which so much of the ultimate extensibility of the material depends, and hence so much of the high constructive value that is due to a just union of ultimate cohesion and toughness, the product of which is represented in 'work done' by the Mallet co-efficients of permanent elasticity and of rupture $T_e$ and $T_r$.

"Although the integrant crystals of steel are much smaller and less pronounced (at least as procured by the Bessemer process) than those of puddled wrought-iron, there can be no doubt that, as an ingot of Bessemer steel cools, its integrant crystals must arrange themselves within the mass in exact obedience to the general law, viz., with their principal axes of symmetry in the direction in which the surface waves of heat have passed off from the mass, that is, *perpendicular to the external surfaces of contour of the ingots*, provided that the cooling be not so rapid as to preclude time for any symmetrical arrangement.

"This arrangement is, in fact, very commonly visible in a broken section of an ordinary ingot of cast-steel of the old process, and markedly so in ingots that have cooled slowly in too hot ingot moulds. In this latter case the stellate and *croissade* arrangement of the crystalline axes as seen in the transverse section of a broken ingot is remarkable and beautiful, and it is a curious example of old ignorance that when this is seen by the Sheffield steel casters they call the steel "burnt," and actually throw it aside as useless until remelted.

"Now, as all cast-steel, Bessemer or other, is crystalline, and as the crystalline axes, when free to dispose their poles in the liquid steel, do take directions in accord with the general law, how is it that when the large ingot of Bessemer steel is hammered out, or rolled out, fibre is not induced as in wrought-iron? How is it that nothing happens but a still greater diminution of the size of the crystalline particles—a reduction equal nearly in all dimensions—and which seems to have no visual limits, as the reduction of the size of the piece is continued by the hammer or the rolls, until at last the microscopic fineness of the crystal gives that character of silvery whiteness and lustre to the naked eye, by which the fracture of a very small piece of forged steel, as a knife blade, is characterised, when, in fact, the crystalline particles can alone be recognised by the microscope?

"In wrought-iron, on the contrary, whatever may be the direction of the principal axes of symmetry of the integral crystals in the puddled mass when cold, they are ultimately found, in accordance with the same general law, *parallel with the direction of least pressure within the mass after it has cooled*, whether that internal pressure has been due to contraction by cooling, or by squeeze of the rolls, or to both.

"If the iron be rolled, say a bar of rivet iron, the lengthway fibre is merely this arrangement of the principal axes of the crystals. The crystallising elements, having at once the property of ductility, as well as that of crystallo-potentiality, having been elongated by rolling, while maintaining the constancy of axial direction.

"Now why does not the same happen with steel, and if it could be made to happen, why should we not obtain a similar great increment of elastic extensibility in the direction of the fibre, that is, of the lengthway of the rolled bar or plate of steel, that we do in wrought-iron?

"We believe the cause of the difference is not any one inherent in the chemical properties of steel as against iron, although it is true that from the greater rigidity of steel at the temperature at which it can be hammered or rolled as compared with wrought-iron, there must *probably* be always a greater difficulty of crystalline arrangement in the steel than in the wrought-iron.

"This is a molecular or physical difference, however, and in this is the real point of difference in the two cases.

"The ordinary process of puddling in wrought-iron is one partly chemical—the robbing the cast-iron of certain of its complex constituents by the air draught and fuel of the furnace, partly mechanical—where, by the continual movement of the rabble or rake, the puddler kneads and mixes up intimately and inseparably, and in a finely divided state, the refined iron, with a certain quantity of slag or silicate of iron, which once thus involved between the crystals never afterwards wholly leaves the mass. In all subsequent operations, whereby the iron is then rolled or otherwise changed in form by pressure or blows while heated, *this fusible slag, disseminated throughout its mass, acts as a lubricator, so to say, in giving freedom and motivity to the re-arrangement of the crystals, whether these be rolled out into long ones* (*fibre*) *or not.*

"Just as the able researches of Sharp, Sorby, and Tyndall, on the mechanism of slaty cleavage, or lamination in rocks, in ice, in clays, in many other bodies, have shown that what is necessary is a heterogeneous and yielding body between the particles of the rigid or more rigid one, whether those of the latter be crystalline or not.

"This Tyndall familiarly illustrates by the way in which the lamellar or fibrous structure is given to common puff paste by the cook, in which the butter plays the part of lubricant between the particles of dough.

"Now let us appeal to the facts of puddled steel, whether these will not bear out these views.

"The process differs in nothing from puddling iron but in stopping it at the right moment; but the working of the 'steel ball' with the rake of the puddler goes on just as with the ordinary 'puddle ball' of wrought-iron, and in either case the silicate of iron is more or less mixed up with the metal. The steel ball is now hammered and rolled into a plate or rod, but now it is found that it has required a certain amount of fibre, that the co-efficients of elasticity (as found by Mallet) are sensibly different in different directions, and greatest in the direction of the rolled length of the plate or rod. Yet what is the difference in the steel itself puddled made from that made by Bessemerising? Nothing particularly, except that the former contains silicate of iron kneaded up in fine division with it, the other does not. In this we believe alone lies the difference in the result of rolling on each."

M. Schott* has established for himself a theory (vol. ii., pp. 291, 549). He contends that each crystal of iron is an octahedron, or rather a double pyramid raised upon a flat square base. The heights of the pyramids are not in the same proportion to their bases in different kinds of steel, and the pyramids become flatter as the proportion of carbon decreases.

Consequently, in cast-iron, and in the crudest kinds of hard steel, the crystals approach more to the cubical form, and the opposite extreme, or wrought-iron shafting, has its pyramids flattened down to parallel surfaces or leaves, which in their arrangement produce what we call the fibre of the iron. Between these limits all variations of heights of pyramids can be observed in the different kinds of steel in which these crystals are arranged more or less regularly and uniformly, according to the quality and mode of manufacture. The highest quality of steel has all its crystals in parallel positions, each crystal filling the interstices formed by the angular sides of its neighbours. The crystals stand with their axes in the direction of the pressure or percussive force exerted upon them in working, and consequently the fracture shows the sides or sharp corners of all the parallel crystals. In reality good steel under the microscope shows large groups of fine crystals like the points of needles all arranged in the same direction, and parallel to each other. If held against the light in a particular direction, each point reflects the light completely, and they thus show a series of parallel brilliant streaks all over the surface. Now the exact parallelism of the pointed ends or of the streaks of light is one of the most decisive tests of a good quality of steel, and this is not visible quite so frequently as might be generally imagined. On the contrary, the majority of steel fractures show crystals arranged in parallel groups or bundles clustered together in several distinct crystalline layers which are not parallel to each other.

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* Iron and Steel Manufacture, by F. Kohn: London, 1869, p. 114.

**Specific Gravity.**—The specific gravity of steel varies between 7·5 and 8·0, and is diminished by hardening for the reasons given in vol. ii., page 282. According to Hausmann, hard unweldable steel from the Solling steel works was reduced from 7·8439 to 7·6770, and weldable steel from 7·8577 to 7·8012 by being quenched at a red heat in cold water. The change of volume is not uniform even for objects of a regular form. Caron* found that upon hardening the same bar many times in succession the hammered bars contracted in length, but increased in other dimensions. Rolled bars and sheets, on the other hand, increased in length. After thirty hardenings the specific gravity was diminished from 7·817 to 7·743.

According to Vickers's investigations the specific gravity of steel also diminished with the proportion of carbon contained in the steel. For example, steel containing 1·25 per cent of carbon showed a specific gravity of 7·823, and steel with 0·33 per cent of carbon 7·871.

The following table shows the specific gravity of Bessemer steel of various degrees of carburisation made at Sandviken in Sweden :—

| | Specific Gravity. | |
|---|---|---|
| Percentage of Carbon. | Soft. | Hardened. |
| 1·5 | 7·785 | 7·736 |
| 1·2 | 7·832 | 7·771 |
| 0·9 | 7·874 | 7·808 |
| 0·6 | 7·879 | 7·807 |
| 0·4 | 7·893 | 7·839 |

**Hardness.**—The hardness of steel varies with its proportion of carbon. The steel poorest in carbon is the least hard, and the steel richest in carbon approaches white pig-iron, but its other properties, strength, fusibility, weldability, &c.,

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* Dingl., Bd. 168. p. 36.

are then modified. For instance, an increase of carbon decreases the tenacity, strength, and weldability of steel, and renders it more easily fusible. Unhardened steel with the proper amount of carbon, 1·4 or 1·5 per cent, is but little harder than wrought-iron. The degree of hardness imparted by the operation of hardening and tempering depends partly on the amount of carbon present, but principally on the difference between the temperature of the heated metal and that of the fluid employed in hardening, and the rapidity with which the cooling takes place. Fluids possessing the highest conducting power for heat produce the greatest hardening. The brittleness of steel also increases with its hardness, and steel which is so hard that it cannot be attacked by a file may be pulverised almost like glass.

Steel of this hardness cannot be used practically, and in order to remove its brittleness it is heated up to a certain temperature, and then cooled, when it will attain the desired degree of hardness. The proper temperature is indicated by the colour of the thin film of oxide formed on the surface of the heated steel, which will be described later on. Steel not requiring a high temperature for attaining the desired hardness is usually the most useful, as it then contains the proper amount of carbon.

The brittleness of steel, which has been induced by hardening, must not be confounded with a deficient tenacity. Brittleness usually originates from impurities of the pig-iron employed, and sometimes from an unequal distribution of the carbon in the steel, and the steel is the more inferior in quality the more brittle it has been made by the operation of hardening.

Foreign substances present may exert a considerable influence upon the hardness of the steel, and this influence may be favourable if the tenacity is not injured in the same time. This is the case when tungsten, for instance, is present, and the influence may be unfavourable if the tenacity is injured or the steel is rendered too brittle. This result is produced by substances such as phosphorus, silicon, &c. V. Waltenhofen* has suggested an excellent mode of determining the hardness of steel by electro-magnetism.

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* DINGL., Bd. 107, pp. 201, 346.

Homogeneous metal (page 5), the Bessemer steel, and some kinds of puddled steel belong to the softest kinds of steel which are poorest in carbon; natural and cement steel in the form of cast- or shear-steel is harder and richer in carbon.

**Strength.**—The tensile strength of steel considerably exceeds that of wrought-iron. The transverse strength is likewise very great, and the crushing strength varies with the hardness of the steel.

The following results* will be found of interest:—

*Comparative Strength of Various Kinds of Iron and Steel in lbs. per Square Inch.*

| | lbs. | |
|---|---|---|
| Ordinary cast-iron (which varies considerably) may be taken at | 18,656 | Templeton. |
| Swedish cast-iron used for ordnance . . . . . . . . | 33,000 | Woolwich Arsenal. |
| Bessemer "iron" in its cast, unhammered state; mean of five trials . . . . . . . . | 41,242 | ,, ,, |

*Wrought-Iron Plates; Mean Breaking Weight with and across the Fibre.*

| | lbs. | |
|---|---|---|
| Yorkshire plates; best . . . . | 59,584 | Fairbairn. |
| ,, ,, ordinary . . | 54,656 | ,, |
| Derbyshire ,, . . . . . . . | 45,136 | ,, |
| Shropshire ,, . . . . . . . | 50,176 | ,, |
| Staffordshire,, . . . . . . . | 45,472 | ,, |
| Mean of four trials of soft iron plates made by the Bessemer process . . . . . . . . . | 68,319 | Woolwich Arsenal. |
| Boiler plates made of very soft cast-steel (approaching in quality to iron) made by the Bessemer process . . . . | 110,000 | Trials at Manchester. |

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* URE's Dictionary of Arts and Mines, vol. iii., 782.

### *Steel Plates; Mean Breaking Weight with and across the Fibre (continued).*

| | lbs. | |
|---|---|---|
| Turton and Sons' cast-steel (¼ inch thick) lengthwise . | 94,289 | Kirkaldy. |
| „ „ „ „ (¼ inch thick) crosswise . . . . . . | 96,308 | „ |
| Mersey Co. puddled steel (2-16th, 3-16th inch thick) lengthwise . . . . . . . . . | 101,450 | „ |
| „ „ „ „ (2-16th, 3-16th inch thick) crosswise . . | 84,968 | „ |
| „ hard puddled steel (¼ inch thick) lengthwise . . . . | 102,593 | „ |
| „ „ „ „ (¼ inch thick) crosswise . . . . . . | 85,365 | „ |

### *Iron Bars Hammered or Rolled.*

| | lbs. | |
|---|---|---|
| English bar iron . . . . . | 55,872 | Templeton. |
| „ „ . . . . . | 56,000 | Rennie's Tables. |
| Swedish „ . . . . . | 72,000 | „ „ |
| „ „ . . . . . | 72,064 | Templeton. |
| Bessemer iron, mean of eight trials | 72,643 | Woolwich Arsenal. |
| „ „ maximum . . . | 82,110 | „ „ |
| Cast-steel, made by the Bessemer process, in its unhammered state; mean of eight trials . | 63,022 | „ „ |
| Sheffield cast-steel. . . . . | 130,000 | Rennie's Tables. |
| Cast-steel made by Krupp of Essen . . . . . . . . . | 127,320 | Woolwich Arsenal. |
| „ „ „ Captain Uchatius. | 91,955 | |
| Cast-steel made of Nova Scotia iron by the ordinary process. | 128,043 | |
| Bessemer steel; mean of seven trials . . . . . . . . . . | 152,911 | |
| „ „ maximum . . | 162,970 | |

The tensile strength of steel is influenced by the following circumstances:—

*a.* **The Degree of Hardness.**—Whilst good unhardened steel in bars of 1 square inch section ruptures at a strain of about 120,000 lbs. (wrought-iron bears only about 59,000 lbs.), the strength may be increased up to 150,000 lbs. if the steel be properly hardened. On the other hand, the steel will bear a mean breaking weight of 110,000 lbs. only, if rendered too hard. The greatest strength, therefore, is not combined with the greatest hardness.

*b.* **The Amount of Carbon.**—According to Vickers's investigations, the tenacity or cohesion of steel increases with its amount of carbon up to 1¼ per cent, but decreases if the proportion of carbon exceeds 1¼ per cent.

Krupp's cast-steel combines great tenacity with homogeneousness, owing to a most careful mechanical treatment and to its small amount of carbon. The latter circumstance renders the steel more difficult to fuse, and therefore necessitates the employment of smelting furnaces with a draught stronger than usual. A larger amount of carbon facilitates the fusibility of the steel, but decreases its tenacity and weldability. The texture of steel is not modified by the circumstances which render wrought-iron crystalline (vol. ii., page 686); steel poor in carbon is therefore frequently used for replacing wrought-iron; it is, moreover, much stronger.

*c.* **The Mechanical Treatment.**—Steel is stronger and more homogeneous if submitted to an often-repeated and long mechanical treatment. A repeated re-heating of the steel extracts some of the carbon, which is likely to increase the tenacity of the steel, as we have before mentioned. Greater tenacity of the steel, however, is probably caused more by careful mechanical treatment than by its amount of carbon. Wrought-iron is never so repeatedly welded, hammered, and rolled as steel, and therefore is not so homogeneous. Homogeneousness, combined with greater strength and elasticity, has been the reason that of late wrought-iron is so frequently replaced by the varieties of soft steel or fine-grained iron, which, at the same time, possess the property of welding. On the other hand, fibrous wrought-iron produced from white pig is cheaper than fine-grained iron, and answers many purposes. Natural steel has frequently the deficiency of being partially raw, owing to imperfect fining, but it may be improved by repeated welding or re-melting if it is not too raw.

*d.* **The Quality of the Raw Material and the Method of Producing the Steel.**—When repeatedly heated, natural steel often better retains its nature and its carbon in more intimate combination than some kinds of cement steel. The good spathic iron ores of Styria and Carinthia without exception yield a natural steel of good appearance, but the best steel, excelling in weldability, hardness, and tenacity, can only be produced from a certain kind of spathic ores occurring in the lower part of the Erzberg, at Eisenerz in Styria, and of the Hüttenberg in Carinthia. The natural steel produced from these ores differs again in homogeneousness and hardness according to the method of fining employed. The external appearance of the steel does not always indicate its nature, which explains why in many steel works the method of production which has been followed there for a long time is anxiously retained.

*e.* **Foreign Admixtures.**—These admixtures are nearly the same as those which contaminate wrought-iron (vol. ii., page 690), but they act more or less energetically; some of them (tungsten, titanium) are favourable, and others (silicon, sulphur, phosphorus, copper, &c.) are unfavourable. When employing impure pig-iron the foreign substances will accumulate more in the natural or puddle steel than in the fined wrought-iron; a purer pig-iron is therefore usually employed in the production of steel, and for this reason the foreign admixtures are present in less quantity, and are therefore less influential. Steel is also more carefully treated than wrought-iron.

Steel, chiefly the natural steel, is sometimes rendered deficient in uniformity by an intermixture of magnetic oxide in consequence of a bad welding or an imperfect hammering; now and then particles of slag occur in the puddled steel, less frequently in the natural steel. The red-shortness of steel is caused by the presence of copper oftener than of sulphur, and is indicated by cracks at the edges of the steel-bar when drawn out at a red heat and plunged into cold water; the fine cracks include black oxide of iron; they cause a superficial roughness of the bar and are frequently seen only by means of a lens. Rawness of the steel likewise causes cracks on the edges, which, however, may be removed by refining the steel. Good steel is free from cracks at the edges and from black oxide of iron, and the edges are smooth. Cold-shortness is seldom caused by phosphorus for the reason that pure pig-iron is mostly employed, and the cold-shortness in steel is usually caused by burning or cold-hammering the steel, and frequently also by imperfectly fining it.

**Elasticity.**—This property corresponds with hardness, and good steel possesses it in a high degree. The elasticity varies with the hardness, and both properties are combined in the best quality of steel, if the steel is free from impurities, possesses the proper amount of carbon, and is properly hardened by employing a suitable temperature and the proper agent for cooling.

**Behaviour of Steel at Higher Temperatures.**—On heating, steel acquires different colours according to the following scale:—

| *Temperature.* | *Colour.* |
|---|---|
| 220° C. | Pale yellow. |
| 230° | Straw-yellow. |
| 243° | Golden-yellow. |
| 255° | Brown. |
| 265° | Brown dappled with purple. |
| 277° | Purple. |
| 288° | Bright blue. |
| 293° | Full blue. |
| 316° | Dark blue. |

When cooled strongly, steel which has been softened by heating assumes a finer grain and a lower specific gravity, and with steels of the same amount of carbon it will become harder the greater the difference of the temperature employed at the operation of hardening. Such hardened steel may be softened again by re-heating, and it will remain soft if allowed to cool slowly. At an increased temperature steel attains the property of wrought-iron for welding, but the temperature required is not quite so high as that for welding wrought-iron. At the operation of welding, steel loses more or less of its carbon according the mode of production, if atmospheric air is not excluded; upon a longer heating steel becomes burnt, and consequently brittle and coarse-grained. Steel heated too strongly acquires a crystalline texture and crumbles under blows of the hammer. Lighter blows must be used when hammering steel than when treating wrought-iron. Cement steel of inferior quality loses its carbon more easily than natural and cast-steel. The weldability of steel decreases with its proportion of carbon, whilst its hardness increases. Cement steel welds easily, notwithstanding its proportionally large amount of carbon, probably because the carbon is not uniformly distributed and not in intimate combination, and part of it burns out upon heating; cast-steel produced from cemented steel contains its whole amount of carbon in more intimate combination, and can only be welded with difficulty; this cast-steel is sometimes employed for the production of very hard unweldable cast-steel approaching cellular pig-iron (vol. ii., page 561), by melting the steel with an addition of white pig-iron and coal. This steel is then forged at a temperature below the welding heat.

Upon heating steel above the welding temperature it commences to melt, and its fusibility increases with the amount of carbon present; Plattner and Scheerer consider the fusing point of steel to be between 1700° and 1900°, on an average 1850° C. Tunner ascertained the fusing point of the radiated white pig-iron to be 1600°, that of the pure grey charcoal pig-iron 1700°, of hard steel 1850°, and of hard wrought-iron 2000° C. Pouillet has observed lower fusing points (vol. ii., page 527), namely 1050°, of easily fusible white pig-iron, 1100° of white pig-iron difficult to fuse, 1100° of grey pig-iron at the first melting, and 1200° when re-melted, 1250° of spiegeleisen and steel-like pig-iron, 1300° or 1400° of steel, and 1600° of wrought-iron, but these observations require further confirmation.

## Constitution of Steel.

The chemical constitution of steel and the true conditions of its formation are not at present sufficiently explained, and contradictory views are still entertained on this subject; further scientific investigations are required to enable the practical metallurgist to thoroughly control the process and to elucidate many observations which are at present empirical.

Ever since the Swedish chemist, Bergmann, in the second half of last century called attention to the part which carbon plays at the formation of different kinds of iron, steel has been considered as a combination of iron with, in certain limits, a variable proportion of carbon, which proportion, and its more or less uniform distribution, influences the quality of the steel; this view is still very frequently entertained.

Accepting this view, Gurlt* considers steel as a combination of $Fe_8C+Fe$; Tunner† as a combination of $Fe_4C+Fe$; Lohage‡ as certain combinations of carbon ($Fe_{12}C$, $Fe_{20}C$, $Fe_{28}C$), consisting of tetrahedral molecules which admit of hardening, in opposition to compounds forming octahedral molecules which cannot be hardened.

Mayrhofer‖ has suggested the following chemical formulæ for different kinds of steel:—

| | Formula. | Fe. | C. |
|---|---|---|---|
| Hard natural and cast-steel | $Fe_6C$ | 98·16 | 1·84 |
| Cast- and shear-steel, not fit for springs and wire owing to its brittleness | $Fe_7C$ | 98·42 | 1·58 |
| | $Fe_8C$ | 98·61 | 1·39 |
| | $Fe_9C$ | 98·77 | 1·23 |
| | $Fe_{10}C$ | 98·89 | 1·11 |
| Cast- and shear-steel, elastic and fit for springs and wire | $Fe_{11}C$ | 98·99 | 1·01 |
| | $Fe_{12}C$ | 99·06 | 0·94 |
| | $Fe_{13}C$ | 99·14 | 0·86 |
| | $Fe_{14}C$ | 99·20 | 0·80 |
| | $Fe_{15}C$ | 99·25 | 0·75 |
| | $Fe_{16}C$ | 99·30 | 0·70 |
| | $Fe_{17}C$ | 99·34 | 0·66 |
| Soft puddled steel, fine-grained iron | $Fe_{18}C$ | 99·38 | 0·62 |

Compounds below $Fe_{18}C$ can no longer be hardened, and pass into wrought-iron. According to Mayrhofer, welded Brescia steel of the composition $Fe_{10}C$ is more elastic than English cast-steel of the composition $Fe_{12}C$; some English steel for clock springs has the composition of $Fe_{11}C$ or $Fe_{12}C$, and some of this steel that from $Fe_{15}C$ to $Fe_{17}C$.

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* B. u. h. *Ztg.*, 1860, p. 502. Berggeist, 1860, No. 19.

† Leob., Jahrb., 1861, x., 480.

‡ *Zeitschrift des Vereins deutscher Ingenieure*, 1857, p. 268. B. u. h. Ztg., p. 48. Berggeist, 1858, p. 14.

‖ Leob., Jahrb., 1861, x., 437.

A great number of chemical analyses have proved that some kinds of steel of great repute consist of iron and carbon only. Schafhäutl was the first who combated this view, asserting that silicon as well as carbon formed an integral component of steel, and he attempted to prove his theory by chemical analyses; on the other hand, other chemists have found in many good varieties of steel only traces of silicon. It is also still problematical whether the small additions of platinum, nickel, silver, chromium, &c., which by analysis are scarcely traceable, exert that good influence attributed to them upon the sorts of steel known by the names of platinum-steel, silver-steel, &c., or whether the good quality of the steel is due only to suitable treatment. Mayrhofer* and others suppose that these substances combine with injurious admixtures in the steel (sulphur, silicon, &c.), and then separate, thus exerting their favourable influence. Of manganese, at least, such a reaction is known, whilst tungsten and titanium enter the steel in combination, improving its quality. Fremy† suggests that tungsten and titanium retain nitrogen, thus facilitating the formation of steel.

The views on the integral components of good steel have become still more confused since Malberg‡ attempted to prove by experiments on the regeneration of burnt steel (page 19) that carbon did not form an essential component of steel, and that the original good qualities of burnt steel could be reconstituted apparently without the introduction of carbon. Fuchs‖ seemed to be of the same opinion, and he considered the different crystallisation as the essential difference between steel, wrought-iron, and cast-iron. He considered wrought-iron as an aggregation of cubic crystals, cast-iron as an aggregation of rhombohedral crystals, and steel as standing between the two; on hardening the steel, the cubes were transformed into rhombohedrons, and on slowly cooling the reverse took place.

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[*] Oesterr. Ztschr., 1861, p. 374. Leob., Jahrb., 1861, x., 335.

[†] B. u. h. Ztg., 1861, p. 415.

[‡] Dingl., Bd. 138, p. 428. Bwkfd., xvi., No. 45.

[‖] Dingl., Bd. 158, p. 209; 1860, pp. 43, 124.

Fremy[*] has also lately asserted that the formation of steel did not require carbon only, but that carbon could be replaced by substances such as nitrogen, sulphur, phosphorus, silicon, boron, arsenic, &c.; the same opinion had already been expressed by Chevreul[†] in 1829.

As early as 1822 Faraday determined the presence of a certain amount of nitrogen in pig-iron and steel, which was afterwards confirmed by Despretz, Schafhäutl, Marchand, Liebig, Boussingault, Bouis, and others, and particularly Liebig, who suggested that nitrogen was an important agent in the formation of steel. It was previously known that iron would combine with nitrogen; Rogstadius[‡] produced combinations of $Fe_5N$ and $Fe_6N$.

According to Binks, Sanderson a few years ago experimentally proved that iron could be transformed into steel only by the joint reaction of nitrogen and carbon, but not by one of these substances separately; however it has been long known that soft iron can be converted into steel by curburetted hydrogen gas alone (Macintosh's method).

Whilst Fremy maintains that nitrogen enters into combination with steel, Caron[‖] denies that it does, and asserts that nitrogen facilitates the formation of steel indirectly by inducing the formation of cyanogen, which, as has long been known, has a strong carbonising action, either by giving carbon direct to the iron, or by forming cyanide of iron, which is then transformed into carbide of iron and nitrogen. The liberated nitrogen is always capable of forming cyanogen again. The latter view is the most probable, and explains in a natural way the chief cause of the formation of cement or blister-steel, as the carbonising action of carbonic oxide gas, observed by Le Play, Laurent, and Stammer, is far weaker. The carbon of the cement powder combines with the nitrogen of the atmosphere included in the powder or otherwise admitted, at the melting heat of copper (1000° or

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[*] Dingl., Bd. 158, p. 209; 1860, pp. 43, 124. Polyt. Centr., 1861, pp. 796, 935, 994.

[†] Dingl., Bd. 160, p. 130.

[‡] Erdm., Journ. f. pr. Chem., Bd. 86, pp. 31, 307.

[‖] Ibid., ii., 333. Karst., Arch., 1 R., xiv., 446. Dingl., Bd. 160, p. 215.

1170° C.), forming cyanogen, which combines with the alkalies present in the charcoal powder; this compound volatilises, and next has a carbonising action on the surface of the iron. The formed stratum of carbide of iron is porous, enabling the gaseous carbonising agent to attack the interior of the iron.

The formation of blister steel is otherwise explained thus:—The coal powder combines with the included air, and forms carbonic oxide gas, which carbonises the surface of the iron and renders it porous; the carbonic oxide then permeates the porous layer of iron and gradually carbonises the whole mass.

Caron* recommends a cementing powder formed of an admixture of three parts carbon and one part carbonate of baryta; a higher temperature is then required to form cyanide of barium, which is less volatile than alkaline cyanides, and accelerates the cementation (from 3 or 4 hours to ½ an hour) and it is also effective for a very long time, so that the loss of coal need only be replaced from time to time. For steeling the surface of iron, an admixture of lighting gas and ammonia is found very good; this mixture also forms cyanogen, and it is likely that the carbonic oxide and lighting gas employed for carbonisation contained some ammonia.

Gruner,† Rammelsberg (vol. ii., page 310), Baker, and Stuart have also lately denied the existence of nitrogen in steel.

On comparing the different views and facts ascertained respecting the constitution of steel, Zander‡ arrives at the conclusion that probably steel consists of very complicated combinations which are not yet sufficiently investigated; or that it may be considered, in a general sense, as a mixture of chemical combinations of iron and its electropositive representatives (manganese, chromium, nickel, tungsten, aluminium, &c.) with metalloids (carbon, silicon, and boron, or phosphorus, antimony, arsenic, and nitrogen or sulphur), amongst which carbon would take the most prominent place. The properties of steel are modified according to the presence of one or the other of these substances; some of them are injurious, whilst others exert a favourable influence, and they chiefly induce certain properties—hardness, for instance—sometimes at the cost of other properties, such as weldability, elasticity, and tenacity. On these substances also depends the degree of temperature required by the different kinds of steel to bring them to their maximum of hardness and to allow the most easy treatment. Which of the properties in the steel is induced by one or the other of the named substances is not yet known, and the chief aim in the production of steel in general, is always to impart a certain amount of carbon without taking the influence of the other substances much into consideration. The properties of steel are influenced, not only by the the chemical agents, but also by some physical conditions; the greater tenacity of steel, for instance, in comparison with the strength of wrought-iron, is a consequence of the smaller tendency to crystallisation, and, besides, is due to the great density produced by mechanical treatment, and to a greater uniformity, which is obtained by melting the steel for instance.

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* DINGL., Bd. 160, p. 214. B. u. h. Ztg., 1862, p. 118. LEOB., Jahrb., 1863, xii., 65.

† DINGL., Bd. 160, p. 215.

‡ Preuss. Ztschr., xi., 270.

## The Theory of Hardening Steel.

Different investigators have also taken different views on this theory.

Hausmann* suggests that on suddenly cooling the heated steel its molecules change their arrangement; the steel expanded by higher temperature cannot on suddenly cooling contract as quickly as it loses temperature, and consequently its volume remains larger whilst its specific gravity is lowered, and the artificial extension of the molecules causes a tension of the same which shows itself by considerable hardness. On heating the hardened steel the artificial expansion is relaxed and the hardness disappears. The modification which the texture of steel undergoes depends on the difference of temperature used at the operation of hardening, and also on the original quality of the steel. Steel loses its crystalline grain more completely if the texture is very homogeneous before hardening. This is the reason why cast-steel undergoes a greater modification than all other kinds of steel; on properly hardening cast-steel the grain disappears almost entirely, the fracture becomes compact, and sometimes slightly conchoidal. The lustre disappears the more if the steel is very light in colour and its grain very fine.

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* HAUSMANN, Molekularbewegungen, 1856, p. 48.

According to Tunner,* hardened steel contains the carbon as $Fe_4C$, which is distributed in the mass of iron in the form of the finest crystals; on heating the steel the graphite separates more and more in fine crystals, which are not distinctly visible, but are only shown by the darker colour of the fracture. Analysis frequently shows the presence of graphite in steel.

Jullien† supposes that hardened steel contains crystalline carbon, which, on heating the steel, is transferred into amorphous carbon.

A similar view is taken by Hezner;‡ the rectangular wrought-iron on cementing becomes softened and combines with carbon in the form of graphite, and this graphite induces a tendency to crystallise in the rhombohedral form. The cohesion of the rectangular form is thus partially overcome, and the steel becomes a combination of both crystalline systems, as Fuchs (page 22) has already observed. The rectangular crystalline system prevails in unhardened steel, and the rhombohedral system in the hardened steel, and the steel approaches nearer the rhombohedral spiegeleisen the greater its hardness. The specific gravity of rhombohedral iron is lower than that of rectangular iron, which explains the lower specific gravity of hardened steel, and also the softening of steel on heating, as the rectangular system is induced by a higher temperature. Both kinds of iron are present in the steel in a state of tension, and have a different degree of solubility in acids.

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* Leob., Jahrb., 1861, x., 480.

† Bullet. de la Société de l'industrie Minérale, i., 566; ii., 202, 644.

‡ B. u. h. Ztg., 1862, p. 140.

Deville* has started the following theory. Iron and carbon combine at a high temperature, and on slowly cooling each of these substances crystallises by itself; the carbon in the form of graphite which may be separated by means of acids. On hardening, the carbon assumes the amorphous state and a less compact steel results, which may be entirely dissolved in acids. On re-heating the hardened steel crystalline carbon is formed again (following the behaviour of glass on devitrification, or that of the quickly cooled amorphous sulphur, which upon heating to somewhat below 100° C. becomes again octahedral).

Caron† supposes that on hardening steel, iron and carbon will combine more intimately, as hardened steel when dissolved in acids yields less graphitic residue than soft steal. The same behaviour in a smaller and limited degree is induced by hammering the steel, but less by rolling.

Kerl considers it probable that when steel is hardened this chemical reaction takes place, and also at the same time the physical reaction suggested by Hausmann.

## Influence of Foreign Admixtures on the Properties of Steel.

We have before observed that the influence of the foreign substances upon steel is in many cases unfavourable, chiefly by impairing its tenacity and elasticity; this influence is exerted by sulphur, phosphorus, silicon, copper, &c.; other substances have a favourable influence, but it is still doubtful whether they always enter into combination with the steel or merely have a purifying effect by combining with the injurious substances present and thus separating them; this is also the case with pig-iron (vol. ii., page 275).

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* Dingl., Bd. 168, p. 174.

† Ibid., Bd. 168, p. 36.

**Oxygen** and **Water** act less upon steel than upon wrought-iron and grey pig-iron, and **Acids** dissolve steel more or less easily according to whether it is hardened or soft.

**Carbon*** when in contact with steel at a high temperature transforms it into a granular, friable product like pig-iron. The proportion of carbon in the steel essentially determines its chief properties; the hardness of the steel increases with the amount of carbon (page 13), whilst its infusibility (page 19) and weldability decrease. Deductions from Mayrhofer's formulæ show that the softest steel contains about 0·75 per cent of carbon, and the hardest above 1·8 per cent, which is then almost unweldable; the best quality of steel contains 1·4 or 1·5 per cent of carbon.

The following analyses show the amount of carbon in different kinds of steel:—

*a. Analyses of Natural and Puddled Steel.*

| | I. | II | III. |
|---|---|---|---|
| C (chemically combined) | 1·698 | 1·570 | 1·380 |
| C (mechanically mixed) | | | |
| Si | 0·0383 | 0·020 | 0·0065 |
| Mn | — | — | 0·012 |
| Al | — | 0·012 | — |
| Cu | 0·3789 | — | — |
| S | trace | — | — |
| P | — | — | trace |

No. 1. Natural steel (Edelstahl) from Siegen, by Karsten. No. 2. Natural steel from the Sollinger Steel Works, by Lampadius. No. 3. Puddled steel from Königshütte in the Hartz, by Brauns.

*b. Analyses of Cement Steel.*

| | I. | II. |
|---|---|---|
| C (chemically combined) | 0·416 | 1·87 |
| C (mechanically admixed) | 0·080 | |
| Si | — | 0·10 |

No. 1 is soft cement steel from Elberfeld, analysed by Bromeis. No. 2. English blistered steel, analysed by Berthier.

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* Karst., Arch., 2 R., xxv., 218.

### c. *Analyses of Cast-Steel.*

| | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|
| C (chemically combined) | 0·95 | 1·758 | 1·577 | 0·65 | 0·94 |
| C (mechanically admixed) | 0·22 | | | | |
| Si . . . . . . . . . | — | — | — | 0·04 | 0·08 |
| Mn . . . . . . . . . | — | — | — | ? | ? |
| S . . . . . . . . . . | — | — | — | ? | ? |
| P . . . . . . . . . . | — | — | — | 0·07 | 0·11 |

| | VI. | VII. | VIII. | IX. | X. |
|---|---|---|---|---|---|
| C . . . . . . . . . . | 1·089 | 0·775 | 1·50 | 1·18 | 1·275 |
| Si . . . . . . . . . | — | — | 0·60 | 0·33 | 0·213 |
| Mn . . . . . . . . . | 0·070 | trace | — | trace | 0·024 |
| Ni. . . . . . . . . . | 0·070 | 0·210 | — | 0·12 | — |
| Co . . . . . . . . . | — | trace | — | — | — |
| Wo . . . . . . . . . | 0·100 | trace | — | — | — |
| Cu . . . . . . . . . | — | — | — | 0·30 | 0·066 |
| P . . . . . . . . . . | — | — | — | 0·02 | — |
| As . . . . . . . . . | — | — | — | — | 0·007 |

No. 1 is best English steel from Sheffield, analysed by Bromeis. No. 2. English cast-steel, analysed by Karsten. No. 3. The same, being refined by welding and hammering, analysed by Karsten. No. 4. The best French cast-steel. No. 5. French cast-steel of second quality. No. 6. Forged Oriental Damascus steel. No. 7. Old gilded sword blade of Damascus. No. 8. Wootz steel. No. 9. Krupp's cast-steel from a cannon which burst at the first round. No. 10. English cast-steel, analysed by Schafhäutl.*

According to these and other analyses, natural steel contains from 0·9851 to 2·44 per cent of carbon, partly as graphite and partly in chemical combination. Cement steel contains from 0·496 to 1·87 per cent; cast-steel from 0·86 to 1·94 per cent (cast-steel with the higher amount of carbon is not weldable); malleable cast-iron contains from 0·88 to 1·52 per cent; and Tunner's steel, produced at a full red heat, contains from 0·86 to 1·20 per cent of carbon.

Eggertz† has suggested a colorimetric method for the determination of carbon, which in Sweden is successfully employed in connection with the Bessemer process. The determined amount of carbon expressed in tenths indicates the degree of hardness of the Bessemer steel or iron, and is marked on the drawn-out products. The lowest proportion of carbon of Bessemer iron determined in Sweden amounted to 0·08 per cent; if containing 0·5 per cent, the iron is capable of hardening and approaches steel, whilst the hardest kinds of steel used for common purposes seldom contain more than 1·5 per cent. The fine cellular pig-iron which is used for wire drawing plates (vol. ii., page 875) contains up to 3·3 per cent. Damascus steel from Zlabtoust contained 1·25 per cent of carbon and 0·68 per cent of graphite.

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* Erdm., Journ. f. pr. Ch., 1859., Bd. 76, p. 294.

† B. u. h. Ztg., 1863, p. 374. Dingl., Bd. 148, p. 432.

**Sulphur.***—Owing probably to its higher state of carbonisation, steel is somewhat less sensitive to the effect of sulphur than wrought-iron; however, a certain amount of sulphur renders steel red-short and also weldable at a lower temperature. The most simple method is Eggertz's plant† for the determination of the proportion of sulphur in steel by means of a silver plate. By this method it was ascertained that the kinds of steel of highest repute contained from none up to 0·012 per cent of sulphur.

As in wrought-iron (vol. ii., page 691), the proportion of sulphur is frequently unequally distributed in the different parts of a steel bar; and this seems to be the case even in cast-steel, although in less degree.

Caron's‡ investigations also show that the presence of manganese facilitates the separation of sulphur in the processes for producing steel.

**Phosphorus.**—Phosphorus, like sulphur, facilitates the welding of steel, and is rarely contained in steel in such quantity as to render it cold-short, for the reason that phosphoric ores were not employed until the introduction of Heaton's patent process. The first experiments with this new process are encouraging.

Concerning the influence of sulphur and phosphorus on steel, Mr. Bessemer states in a paper read before the Institution of Civil Engineers, that upon carefully analysing different samples of steel, it was ascertained that red-shortness was always produced by sulphur when present to the extent of 0·1 per cent, and that cold-shortness was the result of the presence of the same quantity of phosphorus.

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* Karst., Arch., 2 R., ix., 465; x., 794.

† B. u. h. Ztg., 1862, p. 95.

‡ Dingl., Bd. 168, p. 380.

According to Jullien, phosphorus expels carbon at a high temperature, and deprives the hardened steel of all tenacity. Caron* states that manganese does not assist the separation of phosphorus from steel. Eggertz† determined by his method of analysis from 0·01 to 0·02 per cent of phosphorus, contained in the best kinds of steel. This amount of phosphorus, probably originates from the ash of the fuel, which, according to Caron,‡ may contain from 0·08 to 0·10 of phosphoric acid, depending on the kind of wood and the part of the tree from which the wood is taken.

**Silicon.**—The most varied views are taken by different investigators concerning the influence of silicon on steel. Schafhäutl maintains that a certain amount of silicon is required to enable the steel to be susceptible of hardening; most other investigators contend that silicon may partly replace the carbon, but then it always impairs the tenacity of the steel. The best kinds of steel frequently contain only traces of silicon. Karsten states that so small an amount of silicon as 0·05 per cent modifies the tenacity of the iron, and more so than an equal amount of sulphur and phosphorus.

Jullien states that silicon decreases the tenacity of the steel when cold, renders it softer and more difficult to weld at a higher temperature, and if contained in cast-steel, causes a considerable contraction on cooling, and it also corrodes the moulds. In the common sorts of steel for axles, wheels, boiler plates, &c., a small amount of silicon may be allowed, particularly if the steel is but little hardened. On the other hand, harder steel for tools is made brittle by a small amount of silicon.

Caron recommends the addition of manganese to the raw material as the best means of removing the silicon.

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* Dingl., Bd. 168, p. 380.

† B. u. h. Ztg., 1860, p. 412.

‡ Dingl., Bd. 169, p. 349.

**Manganese.**—The influence of manganese in the production of steel is indirect but most favourable. It facilitates the formation of steel, and purifies it, although only a little enters the steel in combination. Caron states that a larger amount of manganese renders steel brittle and hard, and of crystalline fracture, whilst a small proportion (about 0·005) seems to have a favourable influence, transforming the graphite into combined carbon, thus rendering the hard steel more tenacious and weldable. (In Mayr's steel works at Leoben a very hard and tenacious manganese steel is produced for the manufacture of cutting tools). The chief reaction of manganese, however, is to combine with silicon and sulphur, and to separate in this combination; this is the action it exerts in pig-iron (vol. ii., pages 275 and 302). For this reason additions of brown stone, manganiferous spiegeleisen, carbide of manganese, ferro-manganese, &c., are made chiefly at the production of cast-steel. The manganese in pig-iron also facilitates the formation of steel, for the reason that at the operation of conversion it separates sooner than the carbon (vol. ii., page 836), thus prolonging the process, and helping to show the time when steel with the required amount of carbon is formed. Raw manganiferous pig-iron is therefore preferred to refined metal, which loses the greater part of its manganese. Furthermore, at the steel process manganese produces a thinly liquid slag, which covers the metal and prevents oxidation by the atmospheric air; oxide of manganese is also difficult to reduce, and has not an oxidising reaction; the thinly liquid slag can easily be pressed out, consequently the steel becomes stronger and more compact. The manganese contained in the pig-iron reacts more favourably than an addition of peroxide of manganese, at the puddling process for instance, as the peroxide necessarily becomes transformed into oxide and oxidises carbon. The production of pig-iron rich in manganese has been described in vol. ii., page 403. A large amount of manganese is a proof of the purity of the pig-iron.

Schafhäutl has explained the reaction of manganese in the production of steel in a different manner (vol. ii., page 300).

Mushet employs manganese in combination with tungsten.

Copper is the principal enemy of steel, rendering it red-short; therefore in Sweden, &c., ores containing copper pyrites are excluded as far as possible in the production of iron for cement steel. Eggertz has suggested a practical method for the determination of a small amount of copper in steel. His investigations showed that wrought-iron containing 0·5 per cent of copper was only slightly red-short, whilst steel produced from such iron was so inferior as to be useless. Eggertz found in Dannemora iron 0·03 per cent of copper, and in some kinds of foreign steel about 0·2 per cent.

Arsenic, when present in steel in small quantities, is stated by Schafhäutl to induce greater tenacity and finer grain; larger proportions of arsenic render steel red-short.

**Tungsten.**—It was long known that the celebrated Damascus sword blades contained tungsten (0·05 to 0·1 per cent), and De Luynes* employed an addition of tungsten for the production of artificial damasked steel.

In 1855, Jacob† first produced tungsten steel experimentally on a large scale. The steel showed an exceedingly fine, conchoidal, silk-like fracture; it combined great hardness and density, and was superior in tenacity and weldability to all other steel. Next, tungsten steel was produced on a large scale at Leoben,‡ and in different steel works of Germany,‖ England,§ and France.

A patent has been obtained for the manufacture of metallic tungsten alloys (including tungsten steel) by Mr. R. Oxland¶ as a communication from Messrs. Jacob and Koeller. The steel is prepared by melting with cast-steel, or even with iron only (at the puddling process),** either metallic tungsten, or preferably, what has been termed the native alloy of tungsten, in the proportion of 2 to 5 per cent. The native

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* Bgwkfd., ix., 225.

† Oesterr. Ztschr., 1863, No. 47.

‡ Leob., Jahrb., 1863, xii., 72.

‖ B. u. h. Ztg., 1860, p. 27.

§ Ibid., 1860, p. 336.

¶ Ure's Dictionary of Arts and Mines, vol. iii., 959.

** B. u. h. Ztg., 1861, p. 438.

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alloy is obtained by exposing to strong heat in a charcoal-lined crucible, a mixture of clean powdered wolfram with fine carbonaceous matter; it is a black, steel grey, spongy mass, resembling metallic tungsten. The composition of the alloy is shown in the following statement of the composition of wolfram:—

| Tungstic Acid. | | Oxide of Iron. | | Oxide of Manganese. | | | |
|---|---|---|---|---|---|---|---|
| Tungsten | 76·25 | Iron | 17·75 | Manganese | 6·00 | = | 100·00 |
| Oxygen | 19·06 | Oxygen | 5·07 | Oxygen | 1·71 | = | 25·84 |
| | | | | | | | 125·84 |

Wolfram is sometimes used as an addition to the ore mixture for the production of pig-iron.*

According to Bernouilli,† when an intimate admixture of finely divided grey cast-iron and tungstic acid is heated to a very high temperature, the graphitic carbon is burnt by the oxygen of the tungstic acid and steel is formed, which alloys with the reduced tungsten. No diminution in the amount of carbon was, however, perceptible when the experiment was repeated with spiegeleisen, or ordinary cast-iron, carbon in the combined form being apparently unable to effect the reduction of tungstic acid.

Siewert‡ examined eight samples of so-called tungsten steel; the following analyses show that two of the samples contained no tungsten:—

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. |
|---|---|---|---|---|---|---|---|---|
| Iron . . . | — | — | 95·85 | — | 96·37 | — | — | — |
| Tungsten . | 1·05 | 2·84 | 3·05 | — | 2·71 | — | 4·75 | 0·9 |
| Manganese . | — | — | — | — | trace | — | — | — |
| Carbon . . | — | — | — | 1·04 | — | 1·03 | — | — |

No. 1 is tungsten steel from Vienna. Nos. 2, 3, 4, 5, and 6 such steel from Bochum. No. 7, hard tungsten steel from Döhlen. No. 8, soft tungsten steel from Döhlen.

It is frequently maintained that the tungsten steel, owing to its superior qualities, is particularly adapted for the manufacture of cutting tools, swords, and the fine machinery of watches, and that a small addition of it would improve the inferior kinds of steel.

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* B. u. h. Ztg., 1859, pp. 196, 294; 1860, p. 339; 1861, p. 48.

† BAUERMAN'S Metallurgy of Iron, p. 47.

‡ GIEBEL and HEINTZ, Zeitschrift für Gesammte Naturwissenschaft, xvi., 332.

Appelbaum[*] found the tungsten steel inferior to Huntsman's steel, but superior to common English cast-steel; it could also be more easily welded without the application of artificial fluxes, and on hardening required a higher temperature than the English cast-steel before cooling.

Notwithstanding its reputed qualities, tungsten steel has not been generally introduced, probably owing to the high price and the scarcity of wolfram.[†] Perhaps steel was sold as tungsten steel which did not contain any tungsten, or else its reputed qualities are somewhat exaggerated.

**Titanium.**—According to Mr. Mushet, titanium acts upon steel in the same way as tungsten, when titaniferous iron ores or other iron ores with titaniferous fluxes are smelted for the production of grey pig-iron (not white pig as in this case the most titanium will enter the slag), and the grey pig-iron is worked into natural or cement steel.

Mr. Mushet states that a cement steel of this kind produced from Taranaki titaniferous iron sand (vol. ii., page 327), contained—

| | |
|---|---|
| Iron | 98·66 |
| Carbon | 0·87 |
| Titanium | 0·32 |

The steel is said not to rust.[‡]

Riley[‖] supposes that the titanium is either finely distributed in the steel in an amorphous state, or it is alloyed with the iron.

Titanium, at the production of steel, seems to induce the formation of cyanogen, and its influence, which is beneficial, is perhaps due more to the indirect action than to the actual presence of titanium in the finished product.

More recent observations show that titanium, as well as tungsten, seems to enter steel in larger proportions and to improve its quality.

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[*] B. u. h. *Ztg.*, 1859, p. 392.

[†] Wolfram chiefly occurs in Cornwall, at Puy-les-Vignes near St. Leonhard in the department Haute-Vienne, in Saxony, &c.

[‡] B. u. h. *Ztg.*, 1864, p. 14.

[‖] Ibid., 1864, p. 11.

**Platinum, Silver, Nickel, Iridium, Rhodium, Aluminium,*** &c., are said by Schafhäutl and others to enter steel in smaller proportions and to increase its hardness and tenacity.

Faraday and Stodart found that platinum alloyed readily with steel, and produced a very tough and fine-grained product when present to the extent of 1 per cent. Similar results were obtained with palladium, rhodium, and osm-iridium. As, however, these metals are rare and high in price, it is not probable that these alloys could be introduced on a practical scale (page 22).

### Examination of Steel.†

The appearance of the surface and of the fracture of steel indicates the degree of uniformity, the degree of perfection of the welding, the softness of the steel, and also shows whether the steel contains intermixed veins of iron or not; but the appearance is no guide to the temperature at which the steel is to be treated, in order to obtain a certain degree of hardness and the greatest possible tenacity. For this purpose the steel is suitably forged out into a properly formed (dove-necked) chisel and hardened; the chisel is used for cutting grey and white pig-iron or mill-stones, and observations are taken of the manner in which the chisel will wear out, whether it breaks out easily, &c.

Cement steel in an unhardened state is frequently sorted according to the appearance of its surface and fracture; natural steel is often sorted in the same manner after it has been drawn out to thin bars, which are hardened at a red heat and broken into pieces. The scale of the steel after hardening is sometimes removed by rubbing upon wet wood.

A good hard bar of natural steel, when suddenly cooled, gives a clear sound, whilst fine cracks are formed across the bar; the bar contracts uniformly without becoming crooked, and after throwing off its scale shows a pure fine surface with a peculiar blending of dullish grey with dullish white.

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* DINGL., Bd. 134, p. 157. KARST., Arch., 1 R., viii., 193.

† DINGL., Bd. 77, p. 223. Bgwfkd., iii., 129; ix., 353. Polyt. Centr., 1848, No. 13. Sachs. Bergwerkszeitung, 1854, p. 113.

A moderate blow will break the bar, and its fracture shows a conchoidal appearance, a uniform grain not too coarse or too bright, and the tempering colours characterising the steel appear in concentric rings (the so-called *rose*); this is never seen in wrought-iron. Jullien supposes that these rings are caused by sulphur contained in the steel, but this is not likely to be the case. The tempering colours in the form of concentric rings always appear in fresh, hard steel, and on those places only which on hardening get the above-mentioned cross cracks; and as those colours do not appear on every fracture of the steel bar, their absence does not always indicate the softness of the steel.

At the production of Brescian steel, the formation of these tempering colours is forcibly induced by placing the thinly forged steel bar, after the first hardening, near a fire and pouring water upon it from time to time, when the bar will crack in many places.

A steel bar, containing intermixed iron, becomes crooked on hardening, and the scale adheres faster to the soft places of the bar, which is more difficult to break, showing on the fracture a light, bright, and coarse grain, sometimes intermixed with veins of iron.

The characteristics of red-shortness, cold-shortness, &c., have already been described on page 18.

Steel is sometimes sorted more according to the dimensions than the appearance of the fracture (quality), when an inferior product will be obtained. Saint Edme states that the way to distinguish steel from iron is to immerse it in common nitric acid of 1·34 specific gravity; iron will then evolve gas continually, whilst with steel the evolution of gas ceases suddenly after about 20 seconds.

Cement- and cast-steel will be described later in the volume.

## I. PRODUCTION OF STEEL FROM RAW MATERIALS.

On page 1, we stated that the raw materials for the production of steel might be pig-iron, wrought-iron, and ores; the resulting product frequently requires a further refining, either by re-melting or welding, and a subsequent mechanical treatment (hardening, &c.), as a further preparation for the market.

### 1. Production of Steel from Pig-Iron.

The different methods are classified on page 2.

### A. Tunner's Method of Producing Steel by Raising Pig-Iron to a Glowing Heat with an Admission of Atmospheric Air.

At the commencement of the eighteenth century* it was known that a wrought-iron or steel-like product (malleable cast-iron) could be produced by exposing white pig-iron to a glowing heat whilst in contact with substances capable of giving up oxygen (vol. ii., page 671). In 1855, Tunner's experiments proved that the atmospheric oxygen reacted almost as quickly as the oxygen combined with these substances, and that the formation of iron scale at the operation of glowing could be almost prevented by a properly regulated admission of air. This admission was regulated by means of quartz sand, and sand in grains of different size was employed in different parts.

The glowing is performed in a furnace which is at other times used for converting wrought-iron into cement steel; the quartz sand employed allows the admission of air; 100 cwts. of white pig-iron in the form of bars 7 or 9 lines thick are heated in one box for thirty-five days, when ⅔ of the charge results as steel and hard iron, and ⅓ as soft iron. The consumption of coal amounts to about 10 cwts.; this consumption might be avoided by employing waste gases as fuel. The product of the process is very hard and tenacious but not uniform, and is better suited for use before welding. The steel is well fitted for tyres, &c. Its compo-

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Leob., Jahrb., 1857, vii., 99. A. Brüll, étude sur la fonte malléable, Paris et Liège, 1863.

sition is shown by analysis *a*, and *b* is an analysis of the pig-iron from which the steel was produced.—

| | *a.* | *b.* |
|---|---|---|
| C | 0·855 | 3·34 |
| Si | 0·256 | 1·01 |
| S | — | — |
| Mn | 0·447 | — |

This method of producing steel has never come into general use, as the product is not uniform, and as the process is inferior to other steel processes, particularly to the Bessemer process, and is also very lengthy.

### B. Production of Steel by the Reaction of Oxygen from Atmospheric Air, or other Substances, upon Liquid Pig-Iron.

The different methods include the production of steel in fineries and puddling furnaces, the Bessemer process, the Siemens-Martin process, Heaton's process, and the methods of Uchatius and Obuchow, which, however, are seldom used.

**Natural and Puddled Steel.**—As a larger quantity of oxidising agents (slags) react upon the pig-iron in the puddling process, and as also the atmospheric air cannot be so well excluded as in the finery process, puddled steel is usually poorer in carbon, and consequently softer, than natural steel.

Puddled steel, when repeatedly heated and welded to render it more uniform, is also inclined to lose in hardness, owing to the larger amount of intermixed cinder, which causes an oxidation of carbon, though, on the other hand, it facilitates the welding.* If the production of hard puddled steel is intended, it must be kept richer in carbon at the puddling process, and at the subsequent treatment at higher temperature it then loses so much of its carbon, chiefly by the intermixed slag, that it attains the proper hardness. The quality of the pig-iron, and the mode of puddling, are chiefly of essential influence upon the hardness of the puddled steel. It has been also attempted to produce harder puddled steel by employing in the puddling process suitable fluxes which facilitate the formation of cyanogen (soda, common salt, hoofs of cattle, &c.); but instead of this combination of the puddling process with the cementation, it is cheaper to produce puddled iron and to convert the iron into cement steel; the result is also more certain. On the other hand it has been found advantageous to cement finished articles of puddled steel, such as tyres, rails, &c.*

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* Leob., Jahrb., 1853, iii., 287.

Puddled steel is frequently employed to produce a softer kind of cast-steel, and in comparison with the natural steel is cheaper the more expensive the charcoal; the production of puddled steel, on the other hand, is more expensive than that of puddled iron; this is caused chiefly by the smaller production, the frequent repairs of the furnace hearth, and the uncertainty of the result.

Owing to the progress of the puddling process, tool steel may be produced from puddled steel when employing the purer kinds of pig-iron; at Königshütte in the Hartz, for instance, puddled steel is produced from white radiated pig-iron from Gittelde, which after forging, re-heating, and re-forging is used at Uslar for the production of good cast-steel. In Siegen and Westphalia the varieties of puddled steel are the same price as the best natural steel, and often puddled steel is even preferred to the natural steel if produced from the same pig-iron.†

According to Resch,‡ the natural steel of Styria and Carinthia, which has always been intended to replace the English cement steel, has found a serious competition in the refined steel produced from cement and good puddled steel, as these raw products yield, on refining, a better, harder, and more uniform refined steel, which on repeated treatment will retain its nature as steel better than refined natural steel. Furthermore, a product of as good a quality as English cast-steel has never been successfully produced, on a large scale, from natural steel, although the greatest care has been devoted to experiments on the subject.

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* Leob., Jahrb., 1863, xii, 65. Baul. Anlagen, 3 Jahrg., 1 Lief, p. 13.

† B. u. h. Ztg., 1860, p. 233.

‡ Oesterr. Ztschr., 1863, p. 267.

**Natural Steel and Cement Steel.**—On comparing* these two kinds of steel it will be found that cement steel is mostly cheaper to produce than the natural steel, as the cost of cementation (labour, cheaper fuel, &c.), and the cost of wrought-iron are much lower. Owing to the cheapness of fuel, the production of cement steel is remunerative in this country, although the greater part of the wrought-iron employed is imported from Sweden.

In some cases local circumstances enable natural steel to be produced at a lower price than cement steel.

With respect to the quality of steel (supposing that the same kind of pig-iron has been employed), cement steel is purer than natural steel, as in the finery process for wrought-iron the impurities are more perfectly removed than in the direct fining of natural steel. Natural steel is also less uniform, as the finery process is not sufficiently certain, so that about one-third of the production is too soft and intermixed with iron which must be sorted out; the finery process aims at the production of one sort of steel only, whilst the cementation process produces steel rich or poor in carbon, and 2 or 4 per cent of the production only has to be sorted out and re-cemented. These circumstances explain how it is that cement steel is frequently worked direct, in an unrefined state, into various common articles of steel, and also into different kinds of refined and cast-steel. Whilst the natural steel when drawn out is difficult to sort owing to its fine-grained texture, the coarse laminar texture of raw cement steel facilitates this sorting so much as to yield a reliable material for every sort of cast-steel. Cement steel, when drawn out, assumes a fine-grained texture like that of natural steel, and its fracture shows very great differences in raw cement steel only. When the process is properly conducted good wrought-iron always yields a pure uniform cement steel without any intermixed iron. Cement steel is frequently richer in carbon on the surface of the bar than in the interior; this is sometimes desirable for the manufacture of springs, &c. A bar of cement steel is also more uniform throughout its length than a bar of natural steel, thus facilitating the sorting.

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* Leob., Jahrb., 1853, iii., pp. 301, 307, 313; 1857, vi., 91. Bgwkfd., iii., 151.

It has often been asserted that, on refining, cement steel loses its carbon more easily than natural steel, but this is not confirmed by practice with cement steel of good quality, and it is only the case when the wrought-iron employed for the production of cement steel is imperfectly fined and contains intermixed slag.

The qualities of the cast-steel produced from natural or cement steel depend on the quality of the raw materials, supposing other circumstances to be the same.

We have before mentioned (page 6) that the operation of melting facilitates the homogeneousness of steel more than re-heating and welding; but, nevertheless, refined steel is preferred to cast-steel for various articles. This preference is perhaps due only to old customs in the treatment of steel at the manufacture.

With regard to hardness and tenacity, the Styrian and Carinthian natural steel excel all other steel of this kind, and are less inclined to become soft.*

## PRODUCTION OF NATURAL STEEL IN FINERIES.

The fineries for the production of steel are erected chiefly in the neighbourhood of easily fusible, pure, manganiferous iron ores (Styria, Carinthia, Siegen, Thuringia, Central Alps, &c.); and as it is most advantageous to smelt these ores with charcoal for the production of pig-iron, and to convert the pig-iron into steel also with charcoal, the production is limited owing to the scarcity of charcoal. Just in the same way as the finery process for the production of iron is more and more superseded by the puddling process, the fining of steel is superseded by puddled steel, cast-steel, and cement steel.

We propose now to describe the smelting materials (pig-iron, charcoal, and fluxes), next the apparatus (finery fires, &c.), and, lastly, the methods of fining.

The modifications of the finery process are based chiefly on the behaviour of the pig-iron. The finery process for the production of natural steel is for the greatest part empirical, and its result depends chiefly on the quality of the pig-iron, and on the experience and attention of the finer.

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* Leob., Jahrb., 1853, iii., 302. Oesterr. Ztschr., 1863, p. 267.

The process differs from the finery process for the production of wrought-iron chiefly in the following points :—

1. The finery fire for steel is less deep, and its tuyeres lie lower and have a greater inclination.

2. The melted mass is not broken up but fined below the blast, being covered with a larger quantity of poor thinly liquid slags, thus prolonging the process. Also the finery process for steel requires twice the quantity of fuel and one and a half times the labour of the fining of wrought-iron, and the difference of the cost of producing iron and steel in the fineries is proportionally larger than in the puddling of steel and iron; the puddling of steel is, therefore, considerably more economical than the production of steel in fineries.

3. The charge of pig-iron is melted down in several portions, one after another, in order to accelerate the fining and to control the process; the blast employed is of low pressure. The finery hearth must not be full enough for the smelting mass to reach too near the tuyere.

## Materials for the Production of Natural Steel.

**Pig-Iron.**—As even small amounts of foreign admixtures (page 18) render steel useless, and as these admixtures cannot be so perfectly removed in the steel finery process as in the fining of wrought-iron, the pig-iron is as pure as possible, and manganiferous iron is preferred (vol. ii., page 771). Tunner* has called attention to the Carinthian method of fining steel as showing the influence of the quality of the pig-iron upon the quality of the steel. In former times the very best iron ores were smelted with cheap and good charcoal in low furnaces for the production of pig-iron, but since it became necessary to economise labour, ores, and fuel, the ores were smelted in high furnaces with a greater pressure of blast, thus yielding a less pure iron, although still of excellent quality, but the steel produced from it deteriorated in quality; this deterioration is also partly due to the economy in fuel practised in the fining of steel.

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* Leob., Jahrb., 1853, iii., 296.

The following kinds of pig-iron are used for the production of natural steel:—

1. **White Pig-Iron,** which comes quickly to nature (gaarschmelzig) (vol. ii., page 711), namely, flowery pig-iron and cellular (grossluckig) pig-iron, which is used in the Styrian and Tyrolese steel finery process without any previous preparation, and is the most excellent material for the purpose, as it is easily converted into steel. The cellular iron is required to have large pores, because that with small pores (kleinluckig) is easily transformed into wrought-iron.

2. **Pig-Iron,** which comes slowly to nature (vol. ii., page 711):—

*a.* **Spiegeleisen,** which is generally very pure, and comes less easily to nature without using oxidising fluxes than the preceding kinds of pig-iron. Phosphoric spiegeleisen has lately been produced and sold in some smelting works; and siliceous iron may also have the appearance of spiegeleisen.

*b.* **Very Pure Grey or Mottled Pig-Iron** (vol. ii., page 543), which has been previously refined by the operation of "Hartzerrennen" (vol. ii., page 724).

*c.* **Grey Pig-Iron of the Regular Process.**—On melting down this kind of iron oxidising agents are required to convert it into white iron. The resulting natural steel is less uniform, and requires a careful welding and forging; therefore each finery fire usually requires the use of one hammer. Grey pig-iron produced from a refractory ore mixture is not fit for an advantageous production of steel, as the iron is with difficulty fined and forged.

Formerly only charcoal pig-iron was used for the production of natural steel in the district of Siegen, but now coke produced from washed coal is used to replace part of the charcoal without materially injuring the quality of the resulting pig-iron. When employing coke exclusively, the result was a pig-iron of inferior quality, but still fit for the production of natural steel.

Most of the common coke pig-iron from Westphalia, for instance, is unfit for the production of natural steel, for the reason that it contains too small a proportion of carbon. It melts down sufficiently thinly liquid, but comes to nature before the noxious substances are expelled.

The dimensions of the finery fire, and above all the inclination of the tuyere, must be modified according to the rapidity with which the pig-iron comes to nature. The more slowly the pig-iron fines or comes to nature, the shallower must be the finery hearth and the greater the inclination of the blast; the iron will then melt very thinly liquid, but it is more exposed to the influence of the blast, and thus more easily converted into steel.

**Fuel.**—In most cases charcoal only is used, and in rare cases, in Siegen, for instance, very pure coke at the same time.

**Fluxes.**—Nearly the same fluxes are used as in the finery process for the production of wrought-iron (vol. ii., page 736), namely, rich finery slags, hammer slag; sometimes, also, wrought-iron and steel to facilitate the fining, poor slags, quartz and loam to liquefy the slags, and sometimes Schafhäutl's powder (vol. ii., page 740).

*Zander*[*] supposes that probably in the finery process no chlorine is evolved from Schafhäutl's powder, as no free strong acid is present to decompose the brown stone, which emits oxygen at a lower temperature than that required for melting common salt. The volatilising salt corrodes the furnace walling, and is decomposed chiefly by the steam contained in the products of combustion then forming some muriatic acid, which, owing to its great volatility, has but little influence upon the removal of sulphur. Common salt and brown stone, on the other hand, exert a favourable influence upon the formation of the slag.

## Apparatus and Accessories.

**Finery Fire for the Production of Steel.**—The chief differences between these fineries and those for the production of wrought-iron (vol. ii., page 740), are that they are less deep and have tuyeres of a greater inclination and lying nearer to the hearth bottom; the blast is of lower pressure and is made to facilitate the fining of the mass in the hearth, as the mass is not broken up and not shifted above the blast. The dimensions of the finery hearth are modified more or less quickly according to how quickly the pig-iron comes to nature, and more or less inclination is given to the blast whilst the suitable fluxes are added.

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[*] Preuss. Ztschr., xi., 282.

To retain the temperature in the finery hearths, their bottom is formed of sandstone or of fire-bricks, whilst the side walls are lined with iron plates, except the front side, which is usually formed of several cast-iron plates laid one upon another. The side plates lining the back wall and the side opposite the tuyere incline somewhat out of the fire, thus facilitating the removal of the lump or ball, whilst the upper part of the iron plate supporting the tuyere projects slightly into the hearth in order to conduct the flame nearer to the opposite side. If this tuyere plate has not sufficient inclination, the blast is repelled by the coal, passes before the tuyere out of the hearth, and is apt to melt the tuyere plate, as the temperature of the hearth bottom reacts upon it too much. If the iron comes to nature too slowly, the iron plate lining the back wall is placed in such a manner as to form an obtuse angle with the tuyere plate, and when the iron comes to nature too quickly the two plates are made to form an acute angle.

With regard to its distance from the bottom, and its position and inclination in the hearth, the tuyere has still more influence upon the process than the inclination of the iron side plates. The tuyere projects 4 or 5 inches into the hearth with an inclination of from 15° to 20°, and is directed somewhat towards the front wall where the manipulation is the most difficult, thus keeping up here the required temperature. An inclination of the tuyere greater than 2° or 3° promotes the fining, whilst a less inclination prolongs it. The lower side of the tuyere nozzle is usually slightly shortened (vol. ii., page 744).

Like the finery fires for the production of wrought-iron, those for steel are also sometimes closed and provided with a hearth for preparatory heating, and with hot blast apparatus (Styria).* The preparatory heating stoves are used chiefly for heating the blooms and less for the preparatory heating of the pig-iron, as such heated pig-iron facilitates the formation of steel intermixed with iron.

**Refinery Fire (Hartzerrenn Hearths).**—The mottled or grey pig-iron used in the Carinthian process is refined either in a separate hearth, when the iron is tapped off into moulds and cooled with water, or the pig-iron is refined in the steel finery hearths, in which case water is thrown upon the fused metal and the chilled crust stripped off. Combined with the tapping off, the former method has the advantages of a larger production and a better preservation of the steel finery hearth. When refining twice a greater consumption of fuel takes place, but the loss of iron is less than when fining alone.

The blooms resulting from the steel balls are re-heated for the purpose of hammering them to a certain compactness mostly in the refinery hearth either before or after melting down the pig-iron; in some cases a separate warming stove is at the same time employed for the purpose. As, on hammering, the steel balls emit but little slag (the ball would otherwise be too much decarbonised), they are hard under the hammer and get many small cracks.

For the purpose of drawing out into bars, the blooms are likewise usually heated in the finery fires, and only when the bars are to be of small dimensions are the blooms heated in separate hearths, as with the Carinthian Brescian steel, which is intended for export, and packed up in boxes of 250 and 125 lbs. each. Differing from other warming stoves, those for heating the steel blooms are provided with two cast-iron plates, each 2 feet long, 1 foot broad, and several inches thick; these plates are placed on both sides of the tuyere, thus forming for the blast a passage 2 feet long and 3 or 4 inches wide, which is filled with coal. The blooms to be heated are laid crosswise on these plates and covered with coal whilst applying blast of low pressure. It is generally necessary to heat the steel at a lower temperature than that used for heating wrought-iron, as steel is more easily fusible and liable to burn; on the other hand, shorter and oftener repeated heats are required for drawing out steel to finer dimensions.

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* VORDERNB., Jahrb., 1842, p. 64. TUNNER, Stabeisen und Stahlbereitung, 1858, ii., 226.

The forging of the steel blooms requires great care; if heated too strongly, they are cooled somewhat by being allowed to remain on the anvil whilst water is thrown upon them; some blows with the hammer are then applied, when the blooms will either become consolidated or still crumble too much. In the latter case, they are cooled somewhat more, and some blows of the hammer are given to try again to consolidate them, when they are sometimes found to be too cool, requiring a fresh heating. Some raw blooms must be repeatedly heated before they become consolidated. This operation may be less carefully performed if the natural steel is to be hardened.

Hammers are employed for shingling the balls, and also for drawing out the blooms; the usual hammers are 5 or 6 cwts. in weight, and make from 70 to 120 blows in the minute, having a stroke of about 2 feet. For dividing the balls into blooms, hammers weighing 7 or 8 cwts. are sometimes employed, and steam hammers for forging larger pieces.

For drawing out steel into bars of small dimensions, lighter hammers, weighing 3 or 4 cwts., are used; and still smaller hammers, weighing only 1 or 2 cwts., are employed for drawing out the thinnest square rods of Brescian steel from ¼ to ¾ inch square; the smallest hammers are lifted 10 inches, and make 200 blows per minute.

### Methods of Producing Steel by Fining in Hearths.

The variations, or methods, of the raw steel fining process are based on the quality of the pig-iron, on the quality of the intended raw steel, and on some local customs in the manipulation.

**The Styrian process** treats white flowery pig-iron, and is simpler; it consumes less coal, and is therefore oftener employed than the Paal and the Carinthian Processes, which treat refined, pure, mottled, or grey pig-iron, and employ more complicated manipulations, consequently the resulting product is harder and more uniform, and requires less frequent refining than the Styrian steel. The **Paal Steel Process** yields the best product, but is very expensive and complicated, and therefore almost obsolete.

**The Tyrolese Process** resembles both the Styrian and the Carinthian processes: it requires more fuel, and causes a greater loss of iron than the Styrian process, but less than the Carinthian; the steel resulting is harder than the Styrian, and softer than the Carinthian steel.

**The Siegen Raw Steel Finery Process** produces an excellent raw steel from spiegeleisen, which, however, is not quite as good as the Austrian steel, owing to the inferiority of the raw material.

Both the **North German** and the **Dauphiné Processes** treat good grey pig-iron, which is converted in one hearth, and in one continued operation, into raw steel. This process consumes less coal than the Carinthian process, but yields steel of inferior quality, owing to the imperfection of the process.

The latter processes, treating iron which comes to nature with difficulty, are at present almost entirely superseded by the cheaper steel puddling process, and the Carinthian and Styrian processes, which are still kept up by the great reputation of their products, are also beginning to be abandoned in favour of the cheaper methods of cementing and puddling steel.

The steel produced by one or the other method of the finery process is drawn out into bars, and whilst still hot it is thrown in a wooden trough large enough to contain several cwts. of steel bars, and through which a continual stream of cold water is kept running; the good hard kinds of steel then prove their quality by becoming cracked and by their sound (page 37); the hardened bars are afterwards broken into pieces of from ½ to 2 feet long, and sorted, according to the appearance of their surface and fracture, into good steel and steel admixed with iron; the former is marketable, whilst the other varieties are used for the production of more or less good soft cast-steel or refined steel.

The raw steel produced by the Paal and Carinthian processes is mostly sold and used in manufacture in the raw state; the other kinds of raw steel require refining before they are of use for manufacturing purposes.

**Chemical Reactions.**—The chief differences between the fining of steel and the fining of iron are explained on page 43. The chemical reactions of the finery process for the production of steel vary according to the time taken by the pig-iron in coming to nature.

Those kinds of pig-iron which come to nature easily (gaarschmelzige) (flowery and cellular white pig) and which contain, besides a small amount of manganese, traces of silicon, become thickly liquid when slowly melted down, and lose so much carbon by the reaction of the blast as to be converted essentially into steel when reaching the bottom of the finery fire, supposing the process to be normal. The melted down iron is then kept for a short time in contact with moderately poor cinder, and coagulates into a compact pasty mass of steel, forming the lump or ball, which is removed from the hearth and divided into several pieces or blooms. If the melted-down mass is broken up and shifted above the blast, as in the fining of wrought-iron, a uniform fining of the single pieces is impossible, and the decarbonisation is too strong. On re-heating and forging the blooms the very small quantity of slag contained in the steel mass can be perfectly expelled without greatly lessening the amount of carbon by its proportion of oxygen, and without rendering the steel softer. The quantity of pig-iron forming one charge is melted down in different portions, thus facilitating the fining by a more perfect reaction of the blast, and the last melted-down portion will always dissolve the mass upon which it drops, keeping it liquid for some time and then coagulating to a pasty mass. When refining pig-iron of this kind the same chemical actions take place as when refining pig for the production of wrought-iron (vol. ii., page 715); silicon and manganese are mostly separated, and the graphite is converted into chemically combined carbon. The same reactions take place at the "Hartzerrennen" of the Carinthian process, and at the Paal process, in which oxidising fluxes are mixed with the melted-down pig-iron, thus refining it and also separating some carbon.

From this communication it follows that the decarbonisation of white pig-iron which comes to nature easily takes place chiefly above the blast and by its direct influence; on the other hand, with those kinds of pig-iron which on melting become thinly liquid and come to nature with difficulty, the formation of steel is chiefly performed below the blast, on the hearth bottom, by the reaction of substances containing oxygen, and also by the direct influence of the blast, which is conducted at a great inclination to the hearth bottom. This process is more easily performed with spiegeleisen which is rich in carbon and manganese and poor in silicon (Siegen finery process), than with mottled or grey pig-iron (North German and Rivois's method). On melting down spiegeleisen some manganese and iron becomes oxidised, but the complete separation of the manganese and the carbon, so far as it is required, takes place on the hearth bottom by stirring the fused mass with oxidising substances and applying a strong blast; a strong ebullition of the mass will then be apparent.

Mottled pig-iron and grey iron of the regular process contain a larger amount of silicon and less manganese; on melting down these sorts the greater part of the silicon becomes oxidised and the graphite converted into chemically combined carbon, but the whole amount of silicon and carbon can be removed as far as required only by a longer continued reaction of rich slags and of the blast, as the portions of pig-iron which are melted down later on re-impart silicon to the purified fused metal of the hearth bottom.

Darkish grey pig-iron containing silicon, sulphur, and manganese, such as that treated in the Isère department in the Dauphiné, or by Rivois's process, requires first a perfect refining by melting down the pig-iron, whilst reacting upon it by the blast and some oxidising fluxes; according to Lan's investigations, the greater part of the silicon, sulphur, and manganese will then be separated, and the graphite converted into chemically combined carbon, the proportion of which may even increase, and a poor slag is formed by the separation of the oxidised silicon. When mixing the refined melting mass with rich slag, silicon and manganese will be completely removed, and gradually also part of the carbon.

The following are Lan's analyses* of the pig-iron at different periods of the Rivois's steel refinery process:—

| | I. | II. | III. | IV. | V. | VI. |
|---|---|---|---|---|---|---|
| C . . | 5·25 | 5·65 | 4·25 | 5·60 | 5·05 | 3·36 |
| Si . . | 1·57 | 1·50 | 0·48 | 0·60 | 0·85 | 0·60 |
| S . . | 0·30 | 0·25 | 0·11 | 0·13 | 0·19 | 0·17 |
| Mn . | 2·73 | 2·55 | Not determined. | 0·36 | 2·51 | Not determined. |
| Cu | 0·05-0·1 | 0·05-0·1 | 0·1-0·15 | 0·1-0·15 | 0·10 | 0·05 |

No. 1 is the composition of the pig-iron employed. No. 2, the iron after it has been melted down. No. 3, iron at the end of the second period. No. 4, metal after the removal of the slag. No. 5, metal an hour previous to the withdrawal of the first ball. No. 6, steel shortly after the withdrawal of the first ball.

As copper is more difficult to oxidise, its proportion may even increase. Stengel has before called attention to this (page 33), and it is confirmed by the above analyses. On forging red-hot steel, the presence of copper is said to be perceptible in sparks apparently coming from the steel, and which drop down near the anvil.

Irregularities occur in the fining of steel, as in the finery process for wrought-iron.

The regular steel finery process is indicated by the following behaviour:—

On properly melting down the pig-iron with a suitable pressure of blast, the fused mass in the hearth, when touched with an iron bar, will be found to be even, and more or less hard and pasty, but not adhesive, and it will slowly rise up in the hearth. It is covered some inches high with a thinly liquid rather poor slag, a sample of which, when taken with the iron bar, will appear white, and only gradually lose its high temperature. In the course of the process the slag becomes richer, and must be tapped off from time to time and replaced by poor slag, otherwise the resulting steel will be too soft, chiefly if rich slag is present at the end of the process.

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* B. u. h. Ztg., 1860, pp. 183, 224, 245.

A modification of the process shows also a different behaviour of the flame escaping from the hearth, as it then carries small portions of slag out of the hearth. The suitable pressure of the blast is about 10 or 15 inches water column. If the pressure is too strong, the blast will permeate the covering of slag in excess, facilitating its decarbonising reaction too much; this must be prevented, particularly when treating pig-iron which comes to nature easily.

The decarbonising also becomes over strong when melting down the pig-iron too slowly. The mass on the hearth bottom then becomes too pasty, and will stick to an iron bar immersed into it; the slag and flame become lighter; the steel resulting at such irregularity of the process is not uniform; the melting down is then accelerated by increasing the blast; the over rich slags are tapped off and replaced by a sufficient quantity of poor slags, or even quartz; the mass may also be cooled by putting cold pieces of pig-iron or wet slags into it, or water may be poured into the tuyere, &c.

On melting down the pig-iron too quickly, or when pieces fly off from the pig-iron to be melted, and fall into the hearth, another irregularity of the process takes place, which in German is termed "Rohgang." In this case the melted mass in the hearth is too thinly liquid; the slag when taken out of the hearth is red hot, and ceases to glow almost immediately afterwards; a few bright points only appear on the dark surface; the flame emitted from the hearth is also modified. The melting down is then protracted, applying blast of lower pressure, oxidising fluxes, and smaller portions, at the same time frequently tapping off the too poor slags; the mass is repeatedly cooled; pieces of pig-iron which have flown off are, if possible, removed from the hearth by means of a tongs, &c.

The following analyses show the composition of slags resulting at the steel finery process:—

| | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|
| $SiO_3$ . . . . | 23·0 | 29·3 | 21·0 | 19·10 | 9·20 |
| FeO . . . . | 45·0 | 40·4 | 70·2 | 69·92 | 84·40 |
| MnO . . . . | 29·0 | 10·0 | 3·5 | 3·80 | 2·30 |
| CaO . . . . | 2·0 | 14·3 | 4·3 | — | 1·40 |
| MgO . . . . | 1·0 | 1·0 | 0·5 | — | 3·00 |
| $Al_2O_3$. . . . | 1·0 | 1·0 | 0·5 | 1·25 | 1·90 |
| $Fe_2O_3$ . . | — | — | — | 4·15 | — |
| C . . . . . | — | — | — | 1·41 | — |

No. 1 is a slag from Allward obtained at the melting down of the pig-iron, analysed by Berthier. No. 2, poor slag from Rives-de-Gier, near St. Etienne, analysed by Berthier. No. 3, rich slag from the same place, analysed by Berthier. No. 4, slag from Sollingerhütte in Hanover, by Lampadius. No. 5, slag from Schishyttan, analysed by Fellin.

According to these and other analyses, the composition of the poor slags stands between

$$3FeO,SiO_3 \text{ and } 3(3FeO,SiO_3) + 2(6FeO,SiO_3),$$

and that of the rich slags is—without oxide of iron,

$$3FeO,SiO_3 + 4(6FeO,SiO_3),$$

and with oxide of iron

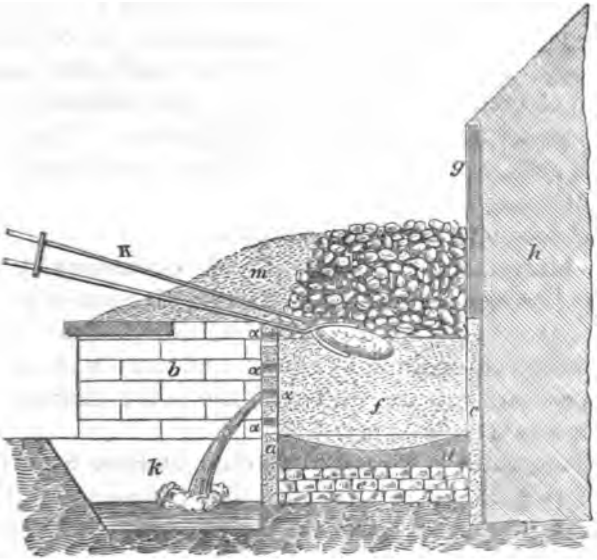
$$4FeO(SiO_3,Fe_2O_3)+2FeO(SiO_3,Fe_2O_3)+6FeO(SiO_3,Fe_2O_3)$$

Such slags as No. 5, poor in silica, may be represented by the formula $17(12FeO,SiO_3)+8(3RO,2SiO_3)$, in which RO expresses the bases isomorphous to the present FeO; the $Al_2O_3$ is calculated together with $SiO_3$.

**The Steel Finery Process with White Pig-Iron which comes Easily to Nature (Styrian Method).**—The pig-iron treated by this method is the white flowery kind sometimes approaching spiegeleisen and sometimes the cellular iron. In the latter case the finery fires are similar to those used in the manufacture of wrought-iron (vol. ii., page 764), and in the former case when the white pig approaches spiegeleisen, finery fires of the construction as shown in Fig. 1 are used.

The iron plate, *a*, lining the front side of the fire, is provided with four apertures, *a*, to run out the cinder. *b*, *b* are the walls enclosing the hearth or fire; *c* is the iron plate lining the back of the hearth; *d*, the hearth bottom formed of a layer of loam 4 inches thick, and resting upon the walled-up foundation, *e*; *f* is a sole of small coal 10 or 12 inches thick; *g* are iron plates facing the back wall, *h*; *k* is a pit for receiving the cinder; *l* represents the coal; and *m* the small coal (Lösch).

FIG. 1.



The tuyere plate and the plate facing the opposite side of the hearth are 21 inches long; the other two side plates of the hearth 28 inches. The tuyere plate inclines 2 inches into the hearth, and its opposite side plate inclines as much out of the hearth. The hearth pit is 23 inches long, 20 inches broad, and 10 or 12 inches deep below the tuyere; the tuyere has an inclination of from 15° to 17°, and projects 4 inches into the hearth. The blast pipes within the tuyere are 15 or 16 lines in diameter, and their nozzles lie 4½ or 5½ inches distant from the nozzle of the tuyere. The blast enters under a pressure of 15 or 16 inches water.

When commencing an operation, 120 lbs. of pig-iron are melted down together with some pounded finery cinder which is thrown upon the coal, whilst the blooms of the previous operation are heated at the same time. As soon as the blooms are forged until only two are left in the fire, a second portion of pig-iron, from 30 to 60 lbs., is charged for melting down. When the hearth is filled up to within 1 or 2 inches from the tuyere and the iron has come to nature, that is, has been converted into steel, the slag is tapped off into a pit filled with water, a shovel-full of wet cinder is thrown into the hearth, the blast is put off, the lump or ball of steel is raised, and then removed in about a ¼ or ½ an hour. The lump is then cut under a hammer into 10 or 12 blooms, which are gradually heated in the finery fire during the period of melting down, whilst the last remaining blooms, are kept hot in a separate glowing furnace. The steel bars which are drawn out under a hammer are thrown into the cooling trough and sorted.

The products are classified thus :—

1. **Meisselstahl (Chisel Steel) occasionally termed Münz- or Rosenstahl (Rose Steel).**—It is mostly in pieces from 4 to 12 inches long; the fracture is clean and conchoidal, has a uniform dull grain, and usually shows a rose. It is ordinarily packed in boxes, and is the dearest kind of unfaggoted Styrian steel.

2. **Edestahl or Rohstahl (Noble or Raw Steel).**—It is in pieces from 3 inches to 2 feet long; the fracture is clean, but no notice is taken of very small, white veins, or somewhat lighter spots in the fracture, accompanied with unsound places or scales on the surface. It is mostly used in making faggoted steel.

3. **Mockstahl, Halbstahl (Half Steel), or Rückenzeug.**—It is difficult to break, and contains intermixed iron which appears on the surface as well-defined veins, or as coarse, light, very bright grains. It is partly employed for inferior descriptions of faggoted steel, chiefly for the outer layers of the piles, and partly sold for forging into scythes.

4. **Rohmittelzeug.**—It is used for inferior kinds of faggoted steel.

5. **Hammereisen (Hammered Iron.)**—It is in pieces which can hardly be broken, and is hard iron rather than steel. It is used for various purposes.

6. **Abfälle or Refudi (Waste pieces).**—They are run

down again in the finery, but sometimes they are worked up into inferior kinds of steel.

The best Styrian scythes are made from the best qualities of steel.

The production of two closed finery fires using hot blast of 364° Fahrenheit, and attended by four workmen, amounts to from 12 to 15 cwts. of steel balls in 16 hours, at a consumption of from 22 to 25 cubic feet of coal; 30 cubic feet are consumed when using cold blast. 85 of raw and 5 of mild steel are often produced from 100 cwts. of pig-iron, the loss being 9·3 per cent. Formerly 100 cwts. of pig-iron yielded only 60 of raw steel, including the chisel steel, 20 of mild, 6 of Hammereisen, and 4 of Rohmittelzeug, at a loss of 10 per cent.

**Carinthian Raw Steel Process.**—The mottled and grey kinds are used for this process; they are either refined by a previous preparatory process or by the steel refinery fire, which we shall presently describe.

The finery fire is 22 or 23 inches long, 23 or 24 inches broad, and the depth below the tuyere to the hearth bottom is from 11 to 13 inches, and to the working bed of stamped charcoal, &c., from 7 to 9 inches. The tuyere side plate is about 3 inches lower than the other three side plates of the hearth. The wind plate, that is the plate opposite the tuyere plate, varies in height, and extends from 2½ to 5 inches above the tuyere plate, for the reason that, in the operation of fining, the pig-iron to be melted down rests upon this plate and the horizontal plate at the same level on the side of it, so that, in melting, the metal may drop from a greater height, and its fining be thereby promoted.

The nozzle of the ordinary circular tuyere is from 16 to 17 lines in diameter, and projects from 3½ to 4½ inches over the tuyere plate. The tuyere inclines from 10° to 16°, with its axis directed towards the middle of the hearth. The blast pipes (either one or two are used) have a diameter of 15 or 16 lines at the nozzle, and lie back from 4 to 4½ inches from the nozzle of the tuyere. The ordinary pressure of the blast is 15 or 16 inches water column.

Much larger quantities of pig-iron are used at a time in the Carinthian than in the Styrian process. 5 cwts. of grey or mottled iron are charged and melted down in about 3 hours. The melted iron is then exposed to the blast until it attains the required purity, as in the ordinary process of refining; after removing the slag, the refined metal is converted into thin plates by throwing water on the surface and taking off the chilled metal in crusts or discs, about 1 or 1½ inches in thickness.

The finery fire is then re-arranged, and the blooms of the ball from the preceding operation are re-heated and hammered, which requires about 1½ hours, causing a loss of 15 per cent. Whilst repeatedly heating and forging these blooms a quantity of from 40 to 70 lbs. of pig-iron, together with a little cinder, is melted down in ½ or ¾ of an hour, and upon this the refined metal of the first operation is added in small quantities, until the whole charge forms on the hearth bottom a more or less pasty or imperfectly fluid mass (Sauer). Coal and slag are then removed from the pasty mass, and it is broken up with a bar and piled into a heap in the centre. If it dries too rapidly, fresh pig-iron must be added, whilst if it is too fluid, oxidation is promoted by the addition of hammer slag. The upper portion of the piled mass, being under the influence of the blast, loses its carbon, whilst the lower part, being in contact with the glowing charcoal forming the hearth, remains in the condition of cast-iron.

After making up the pile, the second portion of the previous lump is re-heated, and when this is done, the contents of the hearth, having subsided into a uniform level surface, are found to be fined sufficiently for the formation of a fresh lump or ball, which is broken out, divided into two parts, and reserved for further treatment. These parts of the lump are subdivided, and finally finished into bars, which are hardened, broken, and assorted in the same manner as in Styria. The chief variety is known as *Kölberlstahl* or *Münzkölberlstahl*, which is the hardest kind. Kölberlstahl in small rods weighing 5 lbs. or 6 lbs., and from 1½ to ¾ of an inch square, is called *Brescianstahl*. The other varieties are known as *Tannenbaumstahl*, long or short, *Stückstahl*, *Mockstahl*, and *Refudi*, or waste steel, which is unsuitable for any purpose.

The Brescian steel is again sorted, chiefly according to its size, but sometimes also according to the appearance of its fracture at the same time, after having hardened the bars and rubbed them on wood.

As in this process the same hearth, in addition to its usual work, is made to do duty alternately as a refinery and re-heating fire, there is considerable waste both of time and fuel. The loss of pig-iron is from 20 to 30 per cent, including the re-heating; the consumption of charcoal is from 40 to 50 cubic feet per cwt. About 75 per cent of the produce is good steel, and is harder and more uniform than the Styrian steel.

Pichler* has improved the old Carinthian process by performing the refining of the pig-iron and the re-heating of the blooms at the same time, thus saving 9·7 cubic feet of charcoal per cwt. of produced steel, besides one-fifth of the working time, and lessening the loss of iron by 10 per cent.

**The Paal, or so-called true Brescian Steel Process** is very similar to the Carinthian process, and differs from it in certain details of manipulation. One point of difference is that, in re-heating the blooms, they are dipped into the molten metal and kept for some time immersed, whereby they undergo a kind of surface hardening by cementation, and acquire hardness and tenacity. The finery fires employed are deeper than those used in the Carinthian process, measuring 10 inches below the tuyere to the hearth bottom of stamped coal, which helps the melted-down metal to keep liquid; also the tuyere has a greater inclination (16 to 20°). This process yields the best steel, but, on the other hand, it consumes nearly 50 cubic feet of charcoal per 100 lbs. of Kölberlstahl, and causes a loss of 15 or 20 per cent.

**The Tyrolese Method** is between the Styrian and Carinthian processes; it has borrowed the construction of the hearth, the mode of refining and of melting down, from the Carinthian process, and the mode of re-heating the blooms and the conduct of the fining process from the Styrian method. The resulting steel and consumption of coal have been mentioned on page 49.

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* Leob., Jahrb., 1862, xi., 203.

The hearths used in the process allow the production of steel and iron alternately without any alteration in the hearth itself or in the direction of the blast.

This process is used in Pillersee.

## Steel Finery Processes with Pig-Iron which comes to Nature with difficulty.

**Siegen Raw Steel Finery Process.**—This process treats spiegeleisen. The finery fires or hearths employed are represented by Figs. 2 and 3. The bottom, *b*, is formed of loam resting upon *a*, and supporting the bottom constructed of fine-grained sandstone put together as closely as possible,

Fig. 2.

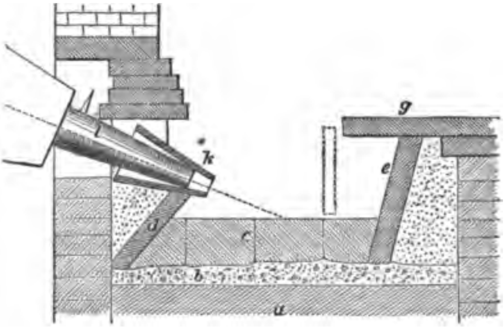
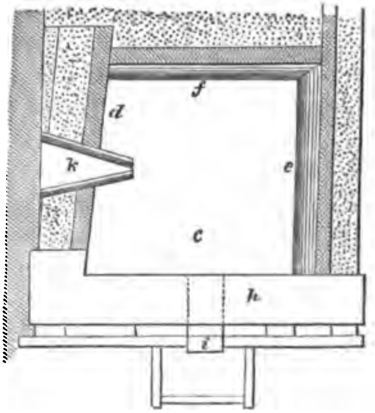


Fig. 3.



the interstices being filled in with powdered sandstone. Much depends upon the quality of the sandstone; it should not be too coarse in grain nor have too great a tendency to crack or fly. Very good stone will last for the production of 8 or 10 lumps or steel cakes. The tuyere plate, *d*, inclines from 12° to 15° inwards; the opposite plate, *e*, is either vertical or inclines a little outwards so as to facilitate the drawing out of the finished product. The back plate, *f*, has, for the same reason, an inclination outwards; *g* is a horizontal iron plate on the top of the plate, *e*; *h* is the working plate; *i* is a box below this working plate provided with a larger hole for emitting the cinder; *k* is the semicircular tuyere 15 or 17 lines wide and 7 or 8 lines high, with an inclination of 2 or 3 degrees. The blast pipe, *l*, 9 or 10 lines in diameter, has an inclination of from 15 to 20 degrees; its nozzle is 1¼ or 1⅛ inches distant from the nozzle of the tuyere. The quantity of blast introduced amounts to 81 cubic feet per minute, with a pressure of 1¾ lbs.

The following is the manipulation of the process:—Over the hearth bottom is spread a thin layer of hammer slag and some rich slag, upon this a layer of burning charcoal, and the hearth is filled up with charcoal. 30 or 40 lbs. of white or mottled pig-iron, which attains the steel nature more speedily than spiegeleisen, are now melted down with the application of a strong blast in order to form the bottom of the lump. This iron will remain thinly liquid for some time, and then gradually attain a pasty consistence, when the poor cinder is tapped off so as to remain on the hearth 2½ inches high only. The charge of spiegeleisen is melted down in small quantities, the first portions gradually decreasing from 80 lbs. to 60 lbs. At the regular process the melted-down spiegeleisen dissolves the metal in the hearth, forming a mass of the consistency of soft butter. The greater part of the slag is tapped off after the melting down of each portion, which causes the flame to become brighter. The fifth portion of spiegeleisen to be melted down weighs 40 or 45 lbs., the sixth 36 lbs., and the seventh 20 lbs. These after charges are made after ascertaining that the process is is going on properly, from the nature of the slag which sticks to the finer's rod, and continues white-hot some time after it is drawn out. The lump ultimately obtained weighs about 4 cwts., and the time required is about 8 hours. This lump is hammered into a cake and divided into seven or eight pieces, which are re-heated in the finery hearth and tilted into bars; these then are hardened, broken, and assorted into good hard steel (noble steel) and steel intermixed with iron (mittelkür). The loss in re-heating is about 20½ per cent; the loss on pig is 30 per cent, 100 lbs. yielding 70 lbs. of steel, of which about ¾ are of good quality and capable of being properly hardened, and the remainder is mild steel or steely iron. From 19 to 20 cubic feet of coal are consumed per 100 lbs. of the product.

In 1863 the production at Siegen was about 127,868 lbs. of natural steel and 465,656 lbs. of puddled steel.

The Siegen raw steel finery process is also used in Sweden,* where the annual production of raw steel is from 500 to 1000 cwts.

**North German Raw Steel Finery Process, Treating Mottled or Grey Pig-Iron.**—This process is similar to the Siegen process, but less inclined tuyeres are employed (10° or 12°), the portions of the charge are smaller (25 or 30 lbs.), and the fining is effected at a strong blast and a lively ebullition, whilst the mass is continually stirred with oxidising substances until the slag sticking to the finer's rod shows the proper white appearance. The coals are then removed from the fire, and the lump, weighing from 160 to 180 lbs., is cooled and treated in the usual manner. If the process is interrupted before the lump attains its proper fineness, the resulting product is very hard without ductility or weldability (so-called mild steel), and is sometimes used for drawing plates, for wire drawing.

In Upper Silesia† and Westphalia a finery fire produces 25 cwts. of raw steel weekly, at a loss of 28 to 30 per cent, and at a consumption of from 30 to 36 cubic feet of charcoal per cwt. of steel.

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* TUNNER, das Eisenhüttenwesen in Schweden, 1858, p. 83. B. u. h. Ztg., 1863. p. 239.

† Preuss. Ztschr., xi., 279.

The finery fire formerly used at Königshütte in the Hartz was 2 feet 10 inches long, 2 feet 2 inches broad, and below the tuyere to the bottom 5½ inches deep. The tuyere inclined 14° and projected 3½ inches into the hearth, conducting the blast to the middle of the hearth in such a manner that, on rebounding, it was directed more towards the front than the other sides of the hearth. A charge consisted of from 2 to 2½ cwts. of white specular pig-iron, 100 lbs. of which yielded 77 lbs. of raw steel, at a consumpsion of 28 or 29 cubic feet of charcoal per cwt. of product.

**The Dauphiné or Rivois's Raw Steel Finery Process.**—Darkish grey pig-iron is treated by this process in charges of 25 cwts.. The finery fires are from 20 to 28 inches long, from 17 to 24 inches broad, and from 23 to 29 inches deep; the bottom lies from 16 to 19 inches below the tuyere. At the commencement of the process the tuyere is in a nearly horizontal position, and later on it is inclined, emitting the blast with a pressure of 2 lines mercury. The pig-iron is melted down in 4 or 5 hours with a strong blast on the hearth bottom of stamped charcoal, and is then refined by means of oxidising substances, and the blast, which is introduced at a strong inclination; and after about 2 hours it becomes thickly liquid and begins to form crusts on the edges. Now begins the first stage of the fining proper; all the poor cinder is tapped off, the coals are removed, and the mass is allowed to cool until it attains a pasty consistency; the metal is then covered again with burning coal and abundant additions of hammer slag are stirred into it, when a violent ebullition will take place, and after from 5 to 7 hours a half-fined spongy crust of pig-iron will be formed on the surface of the metal. This is the point where the second stage of the process commences; the crust is broken up into five or six pieces, which are immersed and turned for about ¼ of an hour in the rich liquid cinder, and thus brought to nature and shingled under the hammer. Oxidising fluxes are then mixed with the mass remaining in the hearth, thus forming a second crust, which is treated like the first, and the process is thus continued until the whole charge is worked up. One operation takes from 18 to 24 hours.

16 cubic feet of charcoal are consumed per 100 lbs. of raw steel at a loss of 8 or 9 per cent. The resulting product requires a most careful sorting, as the first blooms are nearly wrought-iron, whilst the last are still very rich in carbon.

The chemical reactions of this process are explained by Lan* (page 50). Its results are extremely uncertain and the process is fast becoming obsolete.

Mr. Charles Sanderson, of Sheffield, has patented a process which is described in Ure's "Dictionary of Arts and Mines," iii., 757, thus:—"The crude iron is melted on the bed of a reverberatory furnace, and any chemical reagent is added capable of disengaging oxygen during its decomposition. Carbonic oxide or carbonic acid gases are produced by the union of the oxygen with the carbon contained in the fluid iron which is thus eliminated; the gases so produced, being unable to re-enter the metal, either pass off in vapour or act upon the silicates or other earthy compounds which the crude iron may contain, precipitating the metallic part and allowing the earthy matter to flow away as slag; a refined metal is thus produced of very great purity for the production of steel. The metal itself is to some extent decarbonised, the steel is more quickly produced, which secures economy in charcoal, time, and waste of metal, &c.; the purity of the metal also prevents the formation of those deleterious compounds which, when they are incorporated with the steel, seriously injure the quality. Natural steel manufactured from this purified iron has been found of very superior quality and more uniform."

## Production of Steel by Puddling.

The first attempts to produce steel by the puddling process were made in 1835 at Frantschacht† in Carinthia by Schlegel and Müller, who already comprehended all the conditions which later on were found to be required for the conduct of the process of puddling steel. But as at that time the puddling of iron was very remunerative, and as no steel could produced by the puddling process equal in quality to the Carinthian raw steel, the matter was allowed to drop. Also trials made at various other places, at Siegen in 1838, at Eibiswald in 1849, at Hagen in 1840, later on at Wasseralfingen, Limburg, on the Lenne, &c., did not yield satisfactory results, as no uniform product could be produced.* It was not until the year 1850 that good puddled steel was produced in the iron works of Messrs. Lehrkind, Falkenroth and Co. at Haspe† in Westphalia, following the suggestions of the chemist Lohage; and the steel puddling process has since found a general introduction. The process was introduced into England by Mr. E. Riepe, who, according to the official catalogue, was the agent of Messrs. Lehrkind, Falkenroth, and Co. during the Universal Exhibition in 1851. Hence the process is known here as Riepe's process.

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* B. u. h. Ztg., 1860, pp. 181, 441.

† Leob., Jahrb., 1853, iii., 281; 1857, vi., 93. Oesterr. Ztschr., 1855, p. 404.

**Comparison of Puddled Steel with Raw Steel.**‡—Puddled steel is cheaper than raw steel, and sometimes, also, softer (page 39), as the steel balls produced by the puddling process contain more intermixed slag than the balls resulting from the finery process, the removal of which, by repeated reheating and forging, gives rise to a greater oxidation of carbon. Puddled steel is also liable to lose more or less of its carbon according to how quickly after their formation the balls are withdrawn from the furnace, and thus excluded from the influence of the air and slag.

Whilst cement steel may be tempered to any degree of hardness, this may also be done with puddled steel, though with less security. However, advances have been made in the production of puddled steel (the employment of higher temperatures, a suitable construction of the puddling furnaces, the employment of poorer slags and of a suitable pig-iron, proper manipulations, &c.,) which have improved the product so that it may replace raw steel‖ (page 41). It is even possible to produce steel successfully by the puddling process, from common charcoal pig-iron and certain kinds of coke pig, which do not yield a useful steel when treated in finery fires, as the process in reverberatory furnaces, with a judicious selection of the fluxes, allows a more secure conduct of the operation. For this reason the steel finery process is superseded more and more by the steel puddling process, and charcoal is reserved for the blast furnace process, the more so as the puddled steel is cheaper, more easily worked, and applicable to more purposes than the raw steel. Mallet has proved by a number of experiments that puddled steel is not one of the best kinds of steel, but that it may be used for many purposes for which cast-steel would be too expensive.

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* Bgwkfd., xvii., 4.

† Leob., Jahrb., 1852, ii., 186. Polyt. Centr., 1857, p. 603. B. u. h. Ztg., 1860, p. 234.

‡ Leob., Jahrb., 1853, iii., 288. B. u. h. Ztg., 1860, p. 234.

‖ B. u. h. Ztg., 1860, p. 233.

Cementation hardens puddled steel.

The quality of the puddled steel is influenced by the nature of the raw materials and the mechanical treatment of the steel (page 6).

**Chemical Reactions.**—According to the investigations made by Janoyer,* Lan,† Gruner,‡ Schilling,‖ Zander,§ and others, the chemical reactions of the steel puddling process are similar to those of the puddling process for the production of wrought-iron (vol. ii., page 834).

Upon melting down a pure thinly liquid pig-iron with an addition of oxidising fluxes, a refining of the pig-iron takes place, that is, an oxidation of the greater part of silicon, manganese, phosphorus, and, at last, of the sulphur, whereby the slags become poorer, and the proportion of carbon may even increase. When decreasing the temperature and employing a more reducing flame, the metal bath attains a pasty consistency, and upon stirring or puddling the mass properly, an ebullition takes place, and the carbon and remaining foreign substances become oxidised by the slags. The stirring is then continued at an increased temperature until the ebullition ceases, and the formation of the steel is indicated by the light glowing and the weldability of the grains of metal which cohere and sink down in the liquid slag. At the formation of the balls, which commences now, the air must be excluded as much as possible, the oxidising action of the slag must be prevented by employing poorer, more thinly liquid slags, and the balls must be quickly shingled.

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* B. u. h. Ztg., 1860, p. 150.
† Ibid., 1860, pp. 221, 435, 442.
‡ Ibid., 1860, p. 233.
‖ Ibid., 1860, p. 313.
§ Preuss. Ztschr., xi., 279.

The chemical changes going on in the process have been investigated by Lan, Schilling, and others. The following are the results of Lan's investigation :—

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| C . . . . . | 3·980 | 5·220 | 4·690 | 3·50 |
| Si . . . . . | 1·658 | 1·059 | 0·480 | 0·20 |
| S . . . . . | trace | — | — | — |
| Mn . . . . | 1·055 | 0·716 | 0·475 | trace |

No. 1 shows the composition of the pig-iron employed. No. 2, the metal at the end of the second period, when the metal bath was perfectly liquid. No. 3, the metal a quarter of an hour later, before the melting mass began to thicken and strongly rise. No. 4, 25 or 30 minutes afterwards, the metal having risen to its maximum.

Lan* has likewise analysed slags of different periods of the steel puddling process :—

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| $SiO_3$ . . . | 14·50 | 17·50 | 15·00 | 14·50 |
| FeO . . . | 83·12 | 81·14 | 82·00 | 83·50 |
| MnO, CaO . | 2·38 | 1·36 | 3·00 | 2·00 |

The oxygen ratio of acid to base in these slags is 1 : 2—2·5.

The composition of some other slags from the steel puddling process is shown by the following analyses :—

| | I. | II. | III. |
|---|---|---|---|
| $SiO_3$ . . . . . . | 26·0 | 23·5 | 17·8 |
| $Al_2O_3$ . . . . . | 6·8 | 3·3 | 1·8 |
| FeO . . . . . . | 55·9 | 66·0 | 69·1 |
| MnO . . . . . . | 10·5 | 8·4 | 9·4 |
| CaO . . . . . . | 0·6 | — | 0·4 |
| MgO . . . . . . | — | — | 0·4 |
| S . . . . . . . | — | — | 0·9 |

No 1 is a slag from Lohhütte in Siegen, analysed by Schnabel; it results from a process treating very thinly liquid pig-iron which comes to nature difficultly, and yielding a very good, pure puddled steel. The specific gravity of the slag is 3·643. The proportion of oxygen is 16·69 : 14·95; its formula—

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* B. u. h. Ztg., 1860, pp. 183, 224, 245.

$$5(3\mathrm{FeO},\mathrm{SiO_3}) + 3(\mathrm{MnO},\mathrm{CaO})2\mathrm{SiO_3} = 13(3\mathrm{FeO},\mathrm{SiO_3}) + \\ + 2(6\mathrm{FeO},\mathrm{SiO_3}).$$

No. 2 is a slag from the same place produced from a more thinly liquid iron. Its specific weight is 4·127; its proportion of oxygen 13·75 : 16·56, and its formula—

$$4(3\mathrm{FeO},\mathrm{SiO_3}) + 3(2\mathrm{FeO},\mathrm{SiO_3}) + 3(6\mathrm{FeO},\mathrm{SiO_3}).$$

No. 3 is a slag from Firminy obtained at a process carried on with an addition of chloride of sodium, analysed by Gruner.* The proportion of oxygen is 9·25 : 19·16.

Schilling gives the following as the results† of the composition of the metal and slag at different points of the process, as carried out at Zorge in Brunswick. The charge consisted of white pig-iron from Gittelde and grey from Zorge, mixed in equal quantities. The fuel employed in the blast furnace was charcoal, the consumption being at the rate of 100 lbs. for every 87 lbs. of pig-iron produced :—

*Analyses of Iron taken at different Stages of Puddling.*

| | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|
| Graphitic carbon . | 0·08 | 2·13 | 1·11 | — | — |
| Combined carbon . | 2·60 | 1·03 | 1·81 | 2·49 | 2·36 |
| Sulphur . . . . | 0·09 | 0·109 | 0·10 | 0·03 | 0·027 |
| Phosphorus . . . | 0·48 | 0·46 | 0·47 | 0·24 | 0·17 |
| Silicon . . . . | 0·99 | 1·50 | 1·24 | 0·34 | 0·16 |
| Manganese . . . | 2·01 | 1·13 | 1·66 | 0·47 | 0·47 |

| | VI. | VII. | VIII. | IX. | X. |
|---|---|---|---|---|---|
| Graphitic carbon . | — | — | — | — | — |
| Combined carbon . | 2·26 | 1·77 | 1·33 | 1·08 | 0·94 |
| Sulphur . . . . | 0·012 | traces throughout | | | |
| Phosphorus . . . | 0·11 | 0·08 | 0·071 | 0·075 | 0·075 |
| Silicon . . . . | 0·11 | 0·11 | 0·11 | 0·11 | 0·11 |
| Manganese . . . | 0·47 | 0·31 | 0·31 | 0·27 | 0·27 |

No. 1 is white pig-iron from Gittelde.

No. 2, grey pig-iron from Zorge.

No. 3, mean composition of charge.

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* B. u. h. Ztg., 1860, p. 266.

† BAUERMAN'S Treatise on Metallurgy of Iron, p. 344.

No. 4, charge after melting-down, 47½ minutes from the commencement of the process.

No. 5, metal at the commencement of rising, 18½ minutes from the preceding.

No. 6, metal during boiling, 14 minutes later than No. 5.

No. 7, another sample during boiling, 17 minutes later than No. 6.

No. 8, granules of steel commencing to separate, 14¾ minutes later.

No. 9, sample taken at the formation of the first ball, 9 minutes later.

No. 10, sample taken at the formation of the last ball, 9 minutes later.

The metal of the sample No. 3 was tough, strong cast-iron; No. 4, taken after five tools had been heated in rabbling, was stronger than the preceding, but of a tin-white colour; No. 5 was very cellular and resembled white pig-iron, but was slightly malleable; No. 6 was decidedly malleable, and apparently possessed most of the properties of steel, notwithstanding the large amount of carbon present. No increase of carbon was observed in the earlier stages of the process, as recorded by Calvert, Johnson, and Lan. Schilling ascribes this difference to the use of a gas furnace, and the introduction of an excess of air into the furnace by the top blast.

*Corresponding Composition of Slags.*

| | IV. | V. | VI. | VII. |
|---|---|---|---|---|
| Silica . . . . . . . . | 20·98 | 20·51 | 20·12 | 20·34 |
| Phosphoric acid . . . | 5·25 | 5·25 | 5·25 | 5·25 |
| Peroxide of iron . . . | 7·12 | 4·09 | 4·12 | 5·20 |
| Protoxide of iron . . . | 58·98 | 62·03 | 62·14 | 61·20 |
| Alumina . . . . . . . | 2·78 | 2·82 | 2·87 | 2·87 |
| Protoxide of manganese . | 1·64 | 1·64 | 1·64 | 1·64 |
| Lime . . . . . . . . | 1·84 | 2·14 | 2·04 | 1·69 |
| Magnesia . . . . . . . | 1·62 | 1·51 | 1·63 | 1·52 |
| Alkalies . . . . . . . | 0·93 | 0·82 | — | — |
| Sulphuric acid . . . . | trace | | not determined | |
| | 101·14 | 100·81 | 100·68 | 100·58 |

| | VIII. | IX. | X. |
|---|---|---|---|
| Silica | 20·27 | 20·40 | 20·52 |
| Phosphoric acid | 5·25 | 5·25 | 5·25 |
| Peroxide of iron | 5·20 | 4·95 | 6·24 |
| Protoxide of iron | 61·20 | 61·34 | 59·88 |
| Alumina | 2·91 | 3·05 | 2·86 |
| Protoxide of manganese | 1·64 | 1·64 | 1·64 |
| Lime | 2·12 | 1·72 | 1·69 |
| Magnesia | 2·04 | 1·81 | 1·79 |
| Alkalies | assumed at 0·87 | | |
| Sulphuric acid | not determined | | |
| | 101·50 | 101·03 | 100·74 |

In these slags, which are nearly uniform in composition throughout, the oxygen ratio of acid to base is as 11·687 : 18·212, or nearly 1 : 1½ of sesquibasic silicate. This is supposing the peroxide of iron to be in combination with silica, and not replacing it. The large and constant amount of phosphoric acid is ascribed not to the oxidation of phosphorus contained in the pig-iron, which is obviously in too small a quantity to produce such an effect, but to the ash of the wood burnt in the gas generator, and carried over by the draught, owing to the defective arrangement of the ash pit.

## Comparison of the Puddling Process for the Production of Iron with the Steel Puddling Process.

In comparison to the puddling process for the production of wrought-iron, the production of good steel necessitates the following requirements :—

1. **A Pure, Thinly Liquid Pig-Iron,** for the reason that the oxidising reaction of the slags upon the carbon must be limited. From an impure pig-iron, which comes to nature easily, the foreign admixtures could not be sufficiently separated, and if that were done the resulting product would be too poor in carbon. All kinds of white pig-iron poor in carbon which come to nature easily, and also the kinds of grey pig rich in silicon and produced from a refractory ore mixture, as well as the easily fusible sorts of lightish grey sulphurous and phosphoric pig-iron, are therefore excluded from the steel puddling process. The best materials are the pure

manganiferous kinds of pig-iron rich in carbon, such as spiegeleisen (vol. ii., page 712), and flowery pig-iron (vol. ii., page 711), and also grey pig-iron of the regular process (vol. ii., page 713); the latter iron is best when it has been produced from charcoal blast furnaces; on the other hand pure lightish grey coke pig-iron also gives good results, chiefly when containing a larger proportion of manganese, as for example coke pig-iron produced from some Scotch blackband. Clay* obtained equally good results from hot and cold blast pig-iron.

White thickly liquid pig-iron† cannot be employed, chiefly owing to its small amount of carbon, and an addition of spiegeleisen even will not produce a homogeneous product. The greatest effect is obtained by a certain amount of manganese (vol. ii., page 771), contained in the pig-iron, which amount cannot be replaced by the addition of brown stone (page 32); for this reason refined metal is not fit material, as it has been deprived of the greater part of its manganese, and as the remaining part is not sufficient to prevent the oxidation of the carbon during the melting down of the pig-iron. Grey pig-iron, even if converted into white metal by the refining process, loses its carbon more slowly, as the greater part of its silicon must be separated by the slags, before the oxidation of the carbon by means of those slags can take place. According to this behaviour of the pig-iron more or less oxidising fluxes must be added at the operation of melting down, or the thinly liquid pig-iron is mixed with the thickly liquid kind. As the melting down is effected at a very high temperature, a pig-iron rich in silicon would yield a thinly liquid poor slag, strongly attacking the walls and bottom of the furnace; a manganiferous slag does not react so unfavourably, although it is also thinly liquid.

Spiegeleisen and grey pig-iron, which are thinly liquid by themselves, must be brought to the highest possible degree of liquidity by employing a high temperature in order to protract the decarbonisation, as the slag which becomes thinly liquid, at the same time protects the iron from contact with the air; the thinly liquid slag also mixes less with the iron, thus lessening its decarbonising reaction. It appears also that the perfectly liquid state much facilitates the separation of the impurities, and the thinly liquid state allows a prolonged and uniform rabbling, which essentially influences the uniformity of the product. In order to perform the process more quickly and with greater security, the charges at the steel puddling process are taken 50 or 100 lbs. lighter than those used in the puddling process for wrought-iron.

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* B. u. h. Ztg., 1858, p. 163.

† Bgwkfd., 1861, p. 153.

2. **A High Temperature.**—For reasons already given the steel puddling process in its first stages, that is, the melting-down and the stirring or rabbling, is effected at a higher temperature than that used in the puddling process for wrought-iron; on the other hand, the formation of the steel balls is effected at a lower temperature, because at this stage of the process the flame must chiefly be of a reducing nature.

3. **The Slag, with regard to its Quality and Quantity.**—Fluxes, more or less oxidising according to the nature of the pig-iron, are added in the operation of melting-down, and, at the latter part of the puddling process, the presence of a larger quantity of poor (and therefore slightly oxidising) slag, in a state of great liquidity, is chiefly required, in order to keep the finished steel as much as possible from contact with atmospheric air. A basic, thickly liquid slag, such as that used in the puddling process for wrought-iron, would facilitate the fining and impair the hardness and purity of the steel.

The decarbonising action of the slag is regulated by an addition either of rich slags and hammer slag, or of clay,* quartz, and poor slags, if the pig-iron contains a sufficient proportion of manganese to render the slag thinly liquid; in some cases purifying fluxes, such as Schafhäutl's powder, brownstone, common salt, &c., are added if they are not too expensive, as they at the same time facilitate the liquidity of the slags.

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* B. u. h. Ztg., 1858, p. 163.

Lan* and Gruner† recommend the formation of a slag consisting of a double basic silicate of oxides of iron and manganese, containing 8 or 10 per cent of the latter oxide, which slag, being highly fusible, exerts no strong decarbonising action. The slag must be less basic the harder the steel is intended to be. It is preferable to induce the liquidity of the slag by adding alkali or manganese, and not by a larger proportion of silica.

The fluxes are either charged into the furnace together with the pig-iron, which is mostly done when treating white pig in order to hasten the process, or they are added after having finished the melting-down.‡ In the latter case, the quantity of flux to be added depends on the degree of fluidity of the pig-iron, on the temperature of the furnace, and on the quantity of slag produced in the melting-down. With charges of about 350 lbs., from 40 to 60 lbs. of slags of the same process, or of a mixture of re-heating and rich puddling slags, &c. are added, whilst continually stirring the liquid metal. The decrease of temperature thus caused facilitates the fining, and must be corrected by a strong firing until in a ¼ or ½ an hour it has again become sufficiently soft.

An addition of brownstone or of chloride of sodium, or an admixture of both (from 4 to 8 lbs.) in the proportion of 1 to 2 is sometimes added during the operation of melting-down, and, if necessary, repeated later on.

When adding the fluxes after the operation of melting-down, the temperature of the furnace can be less controlled than in the other method, and the removal of the foreign admixtures takes place less perfectly, as on re-heating the mass a decarbonisation and purification take place at the same time. This disadvantage is of less consequence if the pig-iron under treatment is pure, the spiegeleisen in Siegen and Styria for instance. Sometimes, after having made the addition of slag, when the melting mass commences to rise, from 20 to 40 lbs. of pig-iron are charged near the fire-bridge upon a layer of cinder; this pig-iron on melting unites with the boiling mass and increases the proportion of carbon (Riepe's method).

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* B. u. h. Ztg., 1860, pp. 258, 450.

† Ibid., 1860, p. 263.

‡ Oesterr. Ztschr., 1863, p. 270. B. u. h. Ztg., 1855, p. 183; 1860, p. 258.

4. **The different Operations of the Process.**—*a.* **The Melting-down,** as has been before-mentioned, is performed at a higher temperature than that used in the puddling process for wrought-iron; the temperature must be as uniform as possible, and the melting-down is finished in 42 or 45 minutes; the dimensions of the furnace must be suitably chosen so as to allow a shortening of this operation, in order to lessen the oxidising reaction of the atmospheric air.

*b.* **The Stirring or Rabbling,** before the iron commences to rise, is also performed more carefully and at a higher temperature (from 2 to 5 rabbles more are used); throwing water into the furnace would in most cases cool it too much, and so impair the subsequent stages of the process. The particles of metal, which on rising come out of the slag, must be of finer grain than those in the puddling of iron. Phosphoric iron does not form such fine grains as iron free from phosphorus.

*c.* **The Fining** which commences when the metal has risen to the highest point, is performed by repeatedly working the iron mass with the iron tool, at the same time keeping the damper closed and employing a smoky flame; in working iron the damper is kept partly open. When puddling iron the fined iron is shifted from one place to another several times; in the process of puddling steel the operation is usually followed directly by—

*d.* **The Formation of the Balls.**—All the balls, as in the puddling of iron, or only half of them, according to the rawness of the steel and skilfulness of the workmen, are formed before they are shingled; sometimes in cases when the workmen have but little experience, each ball is shingled as soon as it is finished, in the meantime a new ball is formed. The re-heating and forging must be performed carefully at the proper temperature, as in the treatment of natural steel (page 48). In the puddling of iron a further decarbonisation takes place in the operation of forming the balls, but this decarbonisation is avoided as much as possible in the production of puddled steel. The longer time expended in stirring the mass is balanced by the quicker formation of the balls, and the circumstance that the fined metal is not generally shifted. The shingling of steel must be performed more carefully than that of iron. The time consumed in puddling is determined chiefly by the nature of the pig-iron, and the time used in puddling different kinds of iron and steel stands in the following proportion:—

| | *Fibrous Iron.* | *Fine-grained Iron.* | *Steel.* |
|---|---|---|---|
| | minutes. | minutes. | minutes. |
| Melting-down . . . . . | 30—40 | 40—50 | 40—50 |
| Stirring or rabbling . . . | 30—35 | 45—55 | 45—50 |
| Fining . . . . . . . . | 15—20 | 20—25 | 20—25 |
| Shifting or transfer of the fined metal . . . . . | 10 | 3—5 | — |
| Formation of the balls . . | 10 | 10 | 10 |
| | 115—125 | 118—130 | 115—130 |

5. **Consumption of Fuel.**—In puddling iron this consumption amounts to from 100 to 120 per cent, whilst in puddling steel when using good coal in lumps, the consumption of fuel amounts to from 125 to 130 per cent, or even to from 140 to 160 per cent, when inferior coal is employed. This also is effected by the method adopted for cooling the furnace side walls, whether it be done with air or with water. The consumption amounts to 190 per cent, if the coal used for reheating the steel balls is included.

6. **Loss of Iron in the Process.**—The loss in puddling steel is less than in puddling wrought-iron, and depends partly on the nature of the pig-iron (it is larger, for instance, with pig-iron rich in manganese and silicon), on the fluxes, on the conduct of the process, and also on whether the production of an ordinary or of a superior steel is aimed at. The loss in puddling alone averages from 6 to 9 per cent, and it amounts to from 15 to 20 per cent if we include the loss in re-heating.

7. **Production.**—From 1800 to 2000 lbs. of shingled steel balls, or from 1600 to 1900 lbs. of re-heated and rolled steel are produced in 12 hours. When puddling wrought-iron eight or nine charges are made in 12 hours, and six or seven charges when puddling steel.

8. **Cost.**—Though the time used in puddling steel and iron is nearly equal, the cost for steel is somewhat higher, owing to the smaller charges, the frequent repairs of the furnace hearth, the more expensive fluxes, &c. However, according to Gruner, the extra expense for puddling steel does not exceed 20 or 25 francs per ton in comparison to the cost of puddling fibrous wrought-iron, if the same kinds of pig-iron are employed in both processes. But as the pig-iron used for the production of puddled steel is always of good quality, the steel is proportionally higher in price than wrought-iron. 1000 kilos. of puddled iron are produced in 2·2 or 2·5 shifts, whilst the production of such a quantity of puddled steel requires from 2·7 to 3·3 shifts.

9. **The Construction of the Puddling Furnaces.**—The construction of these furnaces is similar to that of the furnaces for the production of fine-grained wrought-iron (vol. ii., page 787), and it differs from the construction of a common puddling furnace in the following points :—

*a.* Single furnaces only are employed, as they permit a better control of the process than double furnaces, and shorten the operation, chiefly in its last stage, in consequence of which the furnace hearth is less attacked, and the oxidising reaction is lessened.

*b.* The furnace hearth is smaller than in common puddling furnaces, the grate is, therefore, proportionally larger, thus rapidly producing high temperatures in the furnace, which is also facilitated by a sufficiently high chimney. The chimney must be provided with a well fitting damper, allowing the perfect exclusion of atmospheric air. The hearth must be 2 or 3 inches deeper, or the fire- and flue-bridges must be so much higher (about 12 or 14 inches projecting above the hearth bottom) in order to be capable of containing more slags without incurring the danger of too much of the slag running over the flue-bridge and the working door, occasioned by the strong rising of the highly carbonised pig-iron; a deep hearth also prolongs the fining.

The hollow iron side walls of the furnace hearth must be cooled either with water or air to protect them from wasting, as a large quantity of poor slag at the high temperature

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of the furnace has a strongly corrosive action. On cooling with water more fuel is consumed (150 lbs. of coal, for instance, per 100 lbs. of steel) than with the cooling by an air draught (only 120 lbs. of coal), and the resulting steel is harder and has a finer grain, as the stronger cooling of the furnace side walls impairs the reaction of the oxide of iron upon carbon.* This mode of cooling is also more under the control of the workmen.

The furnace roof is sometimes, in Styria and Carinthia for instance, placed 4 or 6 inches higher than the usual position of roofs in iron puddling furnaces, in order to keep the oxidising air admitted at a greater distance from the metal bath; in other cases the roof is placed in a lower position with a view of raising the temperature more easily. For cooling purposes the bottom plate is made only 2 or 3 inches thick.

*c.* The flue must be larger in section, and it is important that its roof should be conducted deeper below the edge of the flue-bridge. A long flue facilitates the proper conduct of the temperature. Resch† promotes the uniformity of temperature in the furnace, by placing the flue in such a position that the flue axis deviates from the cross axis of the flue-bridge, and by placing the furnace roof 1½ inches deeper on the back of the furnace than on the front.

*d.* Preparatory heating stoves behind the flue are of less value than in the puddling of iron, as the heated, and thus partially decarbonised, pig-iron is liable to yield steel of too great softness; but the waste flame may to a certain extent be used for the production of steam.

*e.* The grate. It is advisable to place the grate some inches deeper than in the iron puddling furnaces, so that it may contain a larger quantity of fuel, thus allowing a greater reducing reaction if required. The application of blast under the grate has been successful with regard to economy in fuel, and a better conduct of the process. Good mineral coal requires less stirring than wood, and more easily produces the smoky flame required at the last stage of the process.

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* B. u. h. Ztg., 1860, pp. 224, 289.

† Oesterr. Ztschr., 1863, p. 267.

When employing wood as fuel a little coal is sometimes thrown upon the wood at that stage of the process. Step grates are mostly useless, as they admit too much undecomposed air; on the other hand, Spence* has placed two grates one behind the other, the hindmost one 4 inches deeper than the other. During the melting down both ash pits are opened, but later on, when a reducing flame is required, the back ash pit is closed, when the glowing coal on the back grate will combine with the oxygen of the atmospheric air which passes undecomposed through the first grate.

A firing with gas is very advantageous in the puddling of steel; it allows an easy regulation of the oxidising, and has a reducing reaction. To lessen its energetic reaction, the over blast is made to pass along the furnace roof, or it is conducted vertically down, as in the Swedish gas furnaces.

These statements sufficiently prove that it is advisable to employ a separate furnace for the puddling of steel, and not to use a common iron puddling furnace, as is frequently done. The construction of the furnace, as well as the employment of slags of different nature, render the steel puddling process very elastic, and allow the production of softer and harder kinds of steel.

*f*. The dimensions of different steel puddling furnaces† are given by Janoyer, Lan, Gruner, Resch, &c., as follows:—

| | | According to | |
|---|---|---|---|
| | | Janoyer. metres. | Lan. metres. |
| Grate | Length (following the long axis of the furnace) . . | 0·90 | 0·—1 |
| | Breadth . . . . . . . | 1·00 | 0·9 |
| | Height below the furnace roof . . . . . . . . | 0·75 | 0·60—0·75 |
| Fire bridge | Length . . . . . . . . | 1·00 | 0·70—0·80 |
| | Breadth . . . . . . . | 0·37 | 0·25—0·35 |
| | Height . . . . . . . . | 0·27 | 0·35—0·40 |
| Flue bridge | Length . . . . . . . . | 0·30 | 0·35—0·40 |
| | Breadth . . . . . . . | 0·24 | — |
| | Height . . . . . . . . | 0·27 | 0·35—0·40 |

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* B. u. h. Ztg., 1859, p. 448.; 1861, p. 316. DINGL., Bd. 153, p. 140.

† B. u. h. Ztg., 1860, pp. 140, 222, 263.

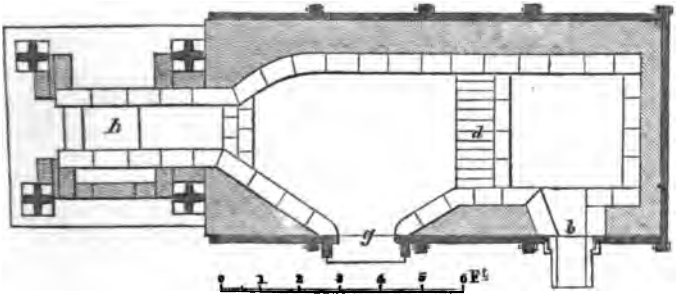
| | | According to Janoyer.<br>metres. | According to Lan.<br>metres. |
|---|---|---|---|
| Hearth | Length | 1·55 | 1·5 —1·6 |
| | Breadth | 1·40 | 1·35—1·4 |
| Flue | Breadth | 0·30 | — |
| | Height | 0·30 | — |
| Height of the working plate above the bottom sole | | 0·27 | 0·20—0·25 |
| Height of the roof above the bottom sole | | 0·70 | 0·65—0·70 |
| „ „ chimney „ „ | | 13—15 | — |
| Section of the chimney . . sq. metres | | 0·25 | — |
| Height of the roof of the flue | | — | 0·55—0·60 |
| Thickness of the slag bottom | | — | 0·10—0·15 |

According to Gruner the steel puddling furnaces, in order to produce higher temperatures, &c., differ from the iron puddling furnaces as follows :—

| | Steel Puddling Furnace.<br>metres. | Iron Puddling Furnace.<br>metres. |
|---|---|---|
| Length of the hearth | 1·55—1·60 | 1·90—2 |
| Proportion of the area of the flue to that of the grate | 1·10 : 1 | 0·06—0·08 : 1 |
| Proportion of the area of the grate to that of the hearth | 1 : 2 | 1 : 2·5 |
| Height of the fire-bridge above the bottom plate | 0·27—0·41 | 0·25—0·27 |
| Thickness of the slag bottom | 0·12—0·13 | — |
| Height of the chimney | 13—15 | — |

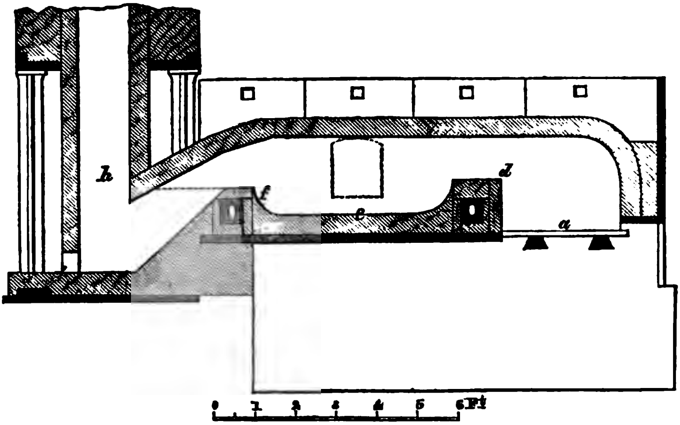
A steel puddling furnace employing mineral coal as fuel, and used at Lohe (Siegen), is represented by Figs. 4 and 5.

FIG. 4.



*a* is the grate; *b*, the stoke-hole; *c*, the fire-bridge cooled with water; *e* is the hearth; *f*, the flue-bridge; *g*, the working opening; *h*, the chimney.

FIG. 5.



Figs. 6 and 7 represent a steel puddling furnace employing wood as fuel, and used at Hirschwang near Reichenau. The furnace is used at the same time for puddling iron. *a* is

FIG. 6.

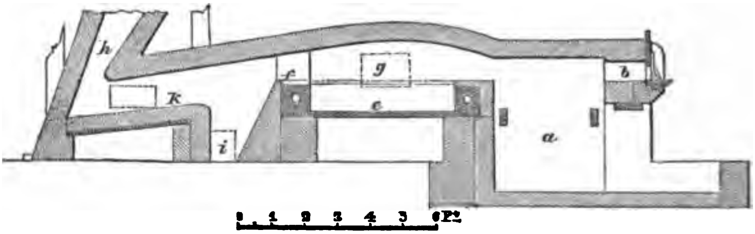
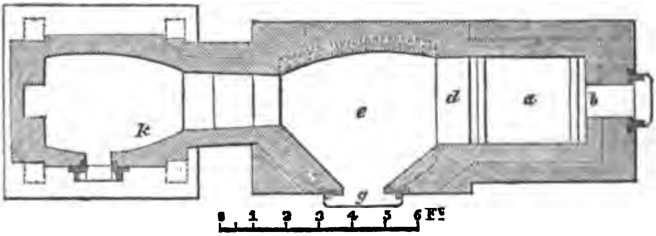


FIG. 7.



the fire-place; *b*, the stoke hole; *d*, the fire-bridge; *e*, the hearth, the sole plate consisting of three parts, the space below being walled up in order to prevent too strong a cooling through the circulation of air. *f* is the flue-bridge; *g*, the working opening; *h*, the chimney; *i*, an opening in the flue; *k*, heating stove, used only when puddling wrought-iron.

**Mechanical Treatment of the Puddled Steel.**—According to the purpose for which the puddled steel is intended, the shingled balls, after being re-heated, are either rolled into bars, &c., and sold in this state, or the bars are refined either by a re-melting or by a repeated re-heating and welding of the piled-up bars. The puddled steel welds better and more easily than cement steel, and has even greater weldability than natural steel; but it is liable to lose its steely nature on welding, according to its original proportion of carbon and the quality of the pig-iron employed (page 39). According to Spence,* pig-iron produced from red iron ore yields very hard puddled steel.

Whilst, according to Clay,† wrought-iron, when repeatedly piled up, increases in tenacity to a certain degree, with puddled steel, this increase takes place only on the first piling up; on repeating this operation with puddled steel, a decrease of tenacity takes place.

When producing large masses, the puddled steel is re-heated in reverberatory furnaces, and treated by steam hammers and rolling mills, but smaller establishments re-heat the puddle steel in fires such as those represented by Figs. 8 and 9. *a* is the hearth; *b*, the working plate; *c*, the tapping hole for the slag; *d*, the tuyere; *e*, the chimney.

The hearth of the re-heating furnaces is usually of sand, like the reverberatory furnaces used for re-heating wrought-iron; sometimes, however, as in Haspe, for instance, they are provided with a bottom of slag, so high as to reach up to the working plate. This slag bottom, on heating, becomes soft, and protects the steel when turned on it.

The operation of forging yields steel of finer grain than that of rolling, but whether forged or rolled the steel must not be heated above redness, or it will break into pieces. Steel piles intended to be rolled into fine dimensions must,

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* B. u. h. Ztg., 1859, p. 448.

† Ibid., 1858, p. 170.

FIG. 8.

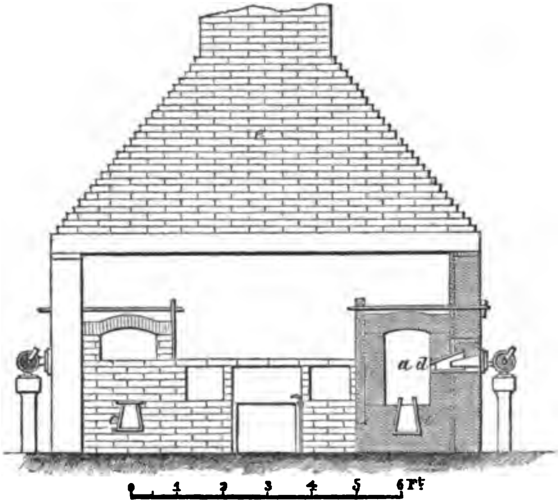
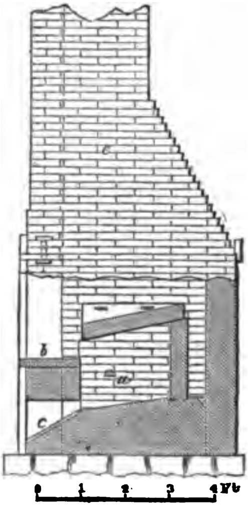


FIG. 9.



therefore, be heated twice, as one heat does not last long enough for the steel to pass through all the grooves required. The larger the steel pieces to be re-heated, the greater will be the difficulty with which they will attain a uniform temperature; it is, therefore, advisable to form the steel balls in the puddling furnaces as small as possible, and to forge them well.

In Westphalia puddled steel is rolled ½ or ¾ of an inch square, and sold in Hamburg under the name of *India steel*; the same steel when hardened is sold under the name of *Mailand steel.*

## The Manipulations of the Steel Puddling Process.

The modifications occurring in the steel puddling process are chiefly caused by the nature of the pig-iron and the quality of the steel to be produced, the quality and quantity of the slags to be added, and the temperature to be employed, the conduct of the process must therefore be chosen accordingly.

The puddling process comprises the following operations:—

1. **The Formation of the Hearth and the Warming of the Furnace.**—As in iron puddling furnaces, the hearth is formed of rich slags, sometimes with an addition of hammer-slag and scraps of burnt iron, about 5 inches high; it is then heated, at a gradually increasing temperature, till the mass, which must be as refractory as possible, begins to frit. When gas is used for firing, the warming of the furnace is effected by commencing with a small fire in the generator, and sometimes applying a small fire in the middle of the hearth at the same time; a weak blast from below is first employed and gradually increased, and the blast on the furnace hearth is employed only after having perfectly dried the furnace walls. As soon as they attain a light-red heat, and the slags a pasty consistency, the furnace may be charged.

Sometimes, in order to raise the temperature of the furnace sufficiently high, some light charges are first puddled for the production of wrought-iron; if possible, thinly liquid pig-iron is employed, and the thin liquidity likewise promoted by suitable fluxes.

2. **The Charging.**—When treating thinly liquid grey pig-iron, a larger quantity of rich slag is thrown into the hearth previous to the charging of the pig-iron. The iron side walls of the furnace are also fettled with rich slag, to keep them as cool as possible in the first period of the process, and to protect them from deposits. When treating thickly liquid white pig-iron, poorer slags are employed. A furnace which has been in operation before, must also be provided with an addition of slag after each charge; and in cases when the furnace is too hot, the softened hearth is cooled by throwing water on it, and by keeping the working door open. When treating spiegeleisen, the addition of slag is frequently made after the melting down. The charge of pig-iron is placed in the middle of the hearth or on the back wall, according to whether the hearth requires cooling or warming; and in order to secure a better result, these charges usually weigh 3 or 3½ cwts. or under, but charges of 4 cwts. are occasionally employed.

3. **The Melting-down.**—The pig-iron is melted down as quickly as possible, whilst the working door is kept closed, and the interstices between door and frame filled up with pounded slag; the opening in the working door is likewise closed by an iron plate. The damper is opened and the fire stirred every 12 or 14 minutes. When gas is used for firing, neutral gases are applied at this period, that is, as much blast is introduced as is required to fully burn the gases. When it is observed through the loop-hole of the working-door, that the greater part of the pig-iron has been melted down, which takes place in from 18 to 24 minutes, the remainder of the pig-iron is raked into the middle of the hearth, and the whole mass is brought into a fluid state by raising the temperature to white-heat, whilst working the hearth with a pointed tool in order to remove solid deposits. The melting-down takes from 35 to 50 minutes, according to the nature of the pig-iron and the manner of firing.

4. **Stirring the Fused Mass.**—This operation varies according to whether the addition of slags is made before or after the operation of melting down. In the latter case, the fused mass is once stirred, the damper closed, and slag of

the same process or an admixture of different slags is added, according to the temperature of the furnace and the liquidity of the pig-iron. Grey pig-iron or spiegeleisen melted down at a high temperature requires a larger quantity of slag than flowery pig-iron; if the furnace, before the melting down, contained a great deal of liquid slag, more cold slags must be added than in cases where the hearth is cool and contains but little liquid slag. When employing an excess of poor slags, the product itself will be only imperfectly purified, and the siliceous slags strongly attack the hearth. The slags are frequently stirred into the fused mass by means of a rabble, together with fluxes of brown-stone and common salt; the stiffened mass is then moved into the middle of the hearth, and the temperature of the furnace increased by opening the damper and closing the working-door until the surface of the mass commences to liquefy separately; the mass is then broken up, distributed on the hearth, and continually stirred with a rabble, when it will soon begin to rise. If this rising continues too long, owing to an injudicious addition of fluxes, wet rich slags are sometimes charged.

When the requisite quantity of slag has been charged together with the pig-iron, and no more slag is required, an addition of brown-stone and common salt, or of common salt only, is given in order to form a liquid slag, and the mass is broken up and continually stirred whilst the damper is kept closed. The metal-bath then begins to thicken and to rise. When puddling pig-iron very rich in carbon, the rising is so great, that part of the slag flows over the working plate and the flue-bridge. To prevent this excessive overflow, the bottom plate is laid deeper in steel puddling furnaces than in those for puddling wrought-iron.

More tools are always used and at a higher temperature when puddling steel than when puddling wrought-iron (vol. ii., page 842). If gas is used for firing, the blast on the hearth must be put off at this period.

5. **The Fining.**—This is the period at which steel is formed, whilst the melting mass has risen to the highest point. The manipulation differs according to whether hard or soft steel is to be produced.

When the production of soft steel is desired, the temperature is slightly increased by partially opening the damper, when a reducing, brilliant white flame will issue from the upper part of the working opening; the mass is then vigorously stirred until a number of hard grains separate from the liquid mass. These grains, having first a red lustre and afterwards a white one, move up and down in the liquid mass, and have a tendency to consolidate and to form snow-white cauliflower-like lumps, indicating that the formation of steel has commenced. The stirring is now continued briskly until the steel grains have consolidated to larger masses, and offer too much resistance to the rabble.

The reddish-coloured slag, which at the commencement sticks but little on the tool, gradually adheres more, attaining a white colour, and including grains which, on contact with air, sparkle and increase in number and size. The slag must remain yellowish red, and raw; a white hot slag, as well as projections of bright wrought-iron upon the steel mass, indicate that the carbonisation has been carried on too far.

As soon as the formation of steel takes place to such a degree that a further stirring becomes difficult and even impossible, the mass is at once quickly transferred and formed into balls, whilst the damper is kept in the same position.

When the production of *hard steel* is required, the stirring is continued at a high temperature until the steel grains formed in the slag, show a welding heat; the damper is now almost entirely closed, so that it becomes impossible to see anything in the furnace, and the workman must be guided by feeling; the spongy mass which has separated from the slag is then collected near the fire-bridge, and here allowed to cool for about five minutes, when it will be of a suitable consistence for balling. The balls are then quickly formed and beaten outside the furnace with a wooden hammer, and afterwards treated under the shingling hammer, commencing with light blows. If the last balls do not possess any more welding heat, the damper must be opened somewhat more, which, however, causes these balls, to become softer. When gas is used for firing, the over blast is put off till this period of the process.

6. **The Formation of the Balls** takes place in the manner described, and varies with the quality of the steel, that is, whether it is hard or soft. A lump of about 40 lbs. in weight is cut off the mass of steel and pressed below the poor slag into a ball; during the shingling of this ball a new one is formed. Only in rare cases are all the balls, or even part of them, formed before commencing the shingling. In order to form a thinly liquid slag, brown-stone is sometimes added before forming the balls.

7. **Shingling the Balls.**—On removing the balls from the furnace and hammering them, they emit a blue flame of carbonic oxide gas. As the steel ball is not yet compact, it is first treated with light blows and then with stronger ones, and is generally forged into a square piece, which is finally hammered, *upsetting* it at the same time. These balls are not allowed to cool so much as those obtained in the finery process. A ball which on shingling falls into pieces or becomes full of cracks is still too raw, and must be returned to the furnace.

8. **Re-heating the Shingled Balls or Blooms.**—For the purpose of drawing them out the blooms are mostly re-heated in reverberatory furnaces, and in some cases in hollow fires.

Sometimes, in order to produce a better product, or when intending to roll out the blooms without piling, they are returned into the puddling furnace from five to fifteen minutes, the damper being half open; they are then turned several times, covered with slag, and taken to the rolls. This method is tolerably cheap; it causes little loss of metal and a small consumption of fuel; it also requires no welding sand, which dissolves iron. As the last balls are mostly poorer in carbon than the first ones, it is advisable to assort the broken steel bars before employing the hardened steel.

The re-heating of the blooms in hollow fires, which is done in Siegen for instance, is performed in the following manner. The hearth is filled up to the working plate with cinder and some coal; two blooms are then kept in a horizontal position in the fire by means of tongs; the space around and above them is filled up to the roof with a mixture of cinder and coal. The blast passes below the blooms through the coals, which are heaped up around the tuyere, and the flame enters the chimney through an opening in the furnace roof. Pounded loam is thrown upon the blooms to protect them from oxidation, and an opening is made in the roof formed of coal above the blooms, for the purpose of watching the latter. The bloom lying nearest the tuyere will first attain the welding heat, and both blooms must be frequently turned. While drawing out the first bloom the second is shifted into its place, and will have a welding heat as soon as the first bloom is sufficiently drawn out.

When both blooms are completely drawn out the bars are usually hardened in a cherry-red state. Blooms which have not attained to a full welding heat, become cracked under the hammer, and must be re-heated.

After having puddled a number of charges for the production of steel, a few more are sometimes puddled for the production of wrought-iron, either for the purpose of regulating the slag-hearth or raising the temperature of the furnace sufficiently high for the steel puddling process. This temperature, owing to the closing of the damper during the last period, may be lowered too much at the commencement of the week, in a furnace that has not been sufficiently warmed, and also at the end of the week in one that had been burnt out too much.

Mr. Riepe, who introduced the steel puddling process into this country, has given the following description of the process :—

"I employ the puddling furnace in the same way as for making wrought-iron. I introduce a charge of about 280 lbs. of pig-iron, and raise the temperature to redness. As soon as the metal begins to fuse and trickle down in a fluid state, the damper is to be partially closed, in order to temper the heat. From 12 to 16 shovelfuls of iron cinder, discharged from the rolls or squeezing machine, are added, and the whole is to be uniformly melted down. The mass is then to be puddled with the addition of a little black oxide of manganese, common salt, and dry clay, previously ground together. After this mixture has acted for some minutes, the damper is to be fully opened, when about 40 lbs. of pig-iron are put into the furnace near the fire-bridge upon elevated beds of cinder prepared for that purpose. When this pig-iron begins to trickle down, and the mass on the bottom of the surface begins to boil and throw out the well-known blue jets of flame, the said pig-iron is raked into the boiling mass, and the whole is then well mixed together. The mass soon begins to swell up, and the small grains begin to form in it and break through the melted cinder on the surface. As soon as these grains appear, the damper is to be three-quarters shut, and the process closely inspected while the mass is being puddled to and fro beneath the covering layer of cinder. During the whole of this process, the heat should not be raised above cherry redness, or the welding heat of shear steel. The blue jets of flame gradually disappear, while the formation of grains continues, which grains very soon begin to fuse together, so that the mass becomes waxy and has the above-mentioned cherry redness. If these precautions are not observed, the mass will pass more or less into iron, and no uniform steel product can be obtained. As soon as the mass is finished so far the fire is stirred to keep up the necessary heat for the succeeding operation, the damper is entirely shut, and part of the mass is collected into a ball, the remainder being always kept covered with cinder slack. This ball is brought under the hammer and then worked into bars. The same process is continued until the whole is worked into bars. When I use pig-iron made from sparry iron ore, or mixtures of it with other pig-iron, I only add about 20 lbs. of the former pig-iron at the later period of the process, instead of about 40 lbs. When I use Welsh, or pig-iron of that description, I throw 10 lbs. of best plastic clay in a dry granulated state on the bottom of the furnace before the beginning of the process; I add at the later period of the process about 40 lbs. of pig-iron as before described, but strew over it clay in the same proportion as just mentioned."

The following are the results of various steel puddling works:—

## 1. The Puddling Process with Direct Firing with Mineral Coal.

*a.* **Lohe* in Siegen.**—White radiated pig-iron is treated in charges of 350 lbs. each, 12 of which are made in 24 hours, causing a loss of 9 per cent of the pig-iron in puddling and of 11 per cent in re-heating the blooms. The puddling furnaces used are represented on page 79, and the blooms are re-heated in hollow fires (page 81). Seven or eight balls, each weighing about 40 lbs., are formed in each charge. 4200 lbs. of pig-iron yield, in the time stated, 3360 lbs. of puddled steel, 78 per cent of which is first quality, and 22 per cent form second and third qualities, being more or less intermixed with iron and less easily broken than the first quality. The consumption of coal per 1000 lbs. of puddled steel amounts to 2000 lbs., that is, 1680 lbs. in puddling, and 320 lbs. in re-heating the blooms. The slags required are added after the melting-down of the pig-iron. The steel is drawn out under hammers. As has been previously stated, the working of one charge takes 2 hours, that is, ¾ of an hour for charging and melting-down, ¼ of an hour for the first stirring, after having given the addition of slags, ¾ of an hour for the further stirring or rabbling, and ¼ of an hour for forming the balls and putting the hearth in order.

*b.* **Geisweide† in Siegen.**—At these puddling works they treat mottled charcoal pig-iron, containing a smaller amount of carbon and manganese, in admixture with 80 lbs. of spiegeleisen, the whole charge amounting to 320 lbs. 68 charges or 272 cwts. of pig-iron yield, in thirteen shifts of 12 hours each, 185 cwts. 20 lbs. of steel and 32 cwts. 85 lbs. of iron, which is puddled in alternation with the steel, at a total consumption of 279 cwts. of coal; 100 lbs. of steel and iron require therefore for their production, 113·4 lbs. of pig-iron and 131 lbs. of coal.

*c.* **At Haspe‡ in Westphalia.**—Eight charges, each of

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* Preuss. Ztschr., ii., Bd. 161.

† Tunner, Leob., Jahrb., 1855, iv., 293.

‡ Ibid.

350 lbs. of charcoal pig-iron, ¼ or ⅓ of which is spiegeleisen, are puddled in 12 hours, causing a loss of 7 or 8 per cent in puddling and 4 or 5 per cent in re-heating; the consumption of coal amounts to about 130 lbs. per 100 lbs. of steel.

The blooms are re-heated in a reverberatory furnace provided with a sole of slag, in which the blooms are turned before they are given to the rolls (page 81). When rolling bars of thin dimensions, which are intended to be sold as such, the re-heating is performed in a reverberatory furnace provided with a hearth of sand.

*d.* **At Königshütte in the Hartz** white radiated pig-iron is treated in charges of 2 cwts., which, if required, are mixed with 20 or 30 lbs. of grey charcoal iron, thus producing a greater liquidity of the iron, and causing a prolongation of the process.

One charge is worked off in 1 hour and 20 minutes, that is 5 minutes are occupied in charging the furnace, 35 minutes in melting down, 20 in rabbling, 15 in forming the balls, and 5 in shingling them.

The yield of one charge amounts to from 180 to 190 lbs. of steel, which is formed into four or five balls; 100 lbs. of puddled steel are obtained, with a consumption of 132 lbs. of coal, and 35 cwts. of steel are produced in 24 hours.

The shingled balls are re-heated in hollow fires, causing a consumption of about 41½ lbs. of coal per 100 lbs. of product. 29 cwts. of steel are produced in 24 hours.

According to an analysis made by Brauns, the puddled steel from Königshütte contained:—

| | |
|---|---|
| C (chemically combined) | 1·380 |
| C (graphitic) | trace |
| Si | 0·006 |
| P | trace |
| Mn | 0·012 |

*e.* **At Vierzon*** the puddling furnaces used are those described by Janoyer on page 78. Four or five charges of 180 kilos. of white "steely" pig-iron each, are puddled in 12 hours at a loss of 5 per cent of the pig-iron. From 750 to 800 kilos. of steel are produced in 12 hours, at a consumption of from 1120 to 1360 kilos. of coal. Nearly the same quantity of coal is consumed when puddling wrought-iron at a loss of 8 or 8½ per cent, making meanwhile about seven charges in 12 hours.

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* B. u. h. Ztg., 1860, pp. 170, 289.

*f.* **In the Department of the Loire.**—The puddling furnaces used are described by Lan* (page 78). One charge consists of 200 kilos. of pig-iron, or 120 kilos. of mottled and 80 kilos. of darkish grey pig, with an addition of from 25 to 30 kilos. of hammer slag, &c. In puddling white pig-iron, only from 15 to 20 kilos. of fluxes are added.

The following is the time that the different operations of the process occupy :—

| | | |
|---|---|---|
| Repairing the hearth and charging the pig-iron, &c. . . . . . | 7 | minutes. |
| Melting down . . . . . . . . | 40—45 | ,, |
| Stirring . . . . . . . . . . . | 25—30 | ,, |
| Bringing to nature . . . . . . | 20—25 | ,, |
| Formation of the balls . . . . | 6—8 | ,, |
| Loss of time in the interval between two charges . . . . . | 5 | ,, |
| Total | 103—120 | minutes. |

The loss of iron in the puddling process amounts to 4 or 5 per cent, and the production in 12 hours from 800 to 900 kilos. From 130 to 150 per cent of coal are consumed per 100 of steel ; that is, 130 when cooling the hollow side walls of the furnace with air, and 150 when using water for cooling the side walls.

*g.* **At Seraing,** charges of 180 kilos. of grey and mottled pig-iron are puddled in 2¼ or 2½ hours, at a loss of 15 per cent of the pig-iron.

*h.* **At Niederbronn on the Lower Rhine,** six or seven charges of 160 lbs. of pig-iron each are puddled in 12 hours. When using furnaces cooled with air, from 1140 to 1145 kilos. of pig-iron and 1250 kilos. of coal per 1000 kilos. of shingled and rolled steel, are consumed ; and from 1120 to 1125 kilos. of pig-iron, and from 1500 to 1600 kilos. of coal are consumed when furnaces cooled with water are used.

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* B. u. h. Ztg., 1860, pp. 222, 289.

### 2. The Puddling Process carried on with Brown Coal.

*a.* **At Neuberg,*** spiegeleisen is treated in charges of 193 kilos., one charge taking 2 hours, or 2 hours 25 minutes. The puddling furnace is cooled with air, and, on an average, 1110 kilos. of pig-iron and 2140 kilos. of common brown coal per 1000 kilos. of raw steel, are consumed. The steel is either only shingled and forged, or shingled, re-heated, and rolled.

*b.* **At Eibiswald†** in Styria, the production of 100 lbs. of puddled steel requires 111·7 lbs. of pig-iron and 160 lbs. of brown coal; 34 cwts. of steel are produced in 24 hours. The blooms are re-heated in open fires with charcoal, at a loss of 10 per cent, and at a consumption of 9·5 cubic feet of coal per 100 lbs. of drawn-out steel.

In the production of wrought-iron 110·9 lbs. of pig-iron and 150 lbs. of brown coal per 100 lbs. of puddled iron, are consumed, and 43 cwts. are yielded in 24 hours; in forging, 110·4 lbs. of blooms and 10·6 cubic feet of soft charcoal per 100 lbs. of bar iron are consumed. The production of steel in 24 hours amounts to 13 cwts., and that of wrought-iron to 15 cwts.

*c.* **At Hirschwang‡** near Reichenau, two experiments with the steel puddling process have been made by way of comparison; the first consists in employing the waste heat for the production of steam, and introducing hot blast before the fire-bridge at the first period of the puddling for fining the iron; and the second in conducting the puddling process without employing the waste heat and without introducing blast. The following results were obtained:—

In the first case 1·078 cwts. of pig-iron, 8·64 cubic feet of wood, and 0·6 lbs. of coal (thrown upon the wood during the fining) were consumed per cwt. of the blooms, 18·84 cwts. of which were produced in 24 hours. In the latter case, the consumption per cwt. of blooms amounted to 1·122 cwts. of pig-iron, 8·53 cubic feet of wood, and 2·5 lbs. of coal, and 18·92 cwts. of steel were produced in 24 hours.

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* B. u. h. Ztg., 1860, p. 283.

† TUNNER, LEOB., Jahrb., 1857, vi., 97.

‡ Oesterr. Ztschr., 1863, p. 270.

### 3. Puddling Steel with Gas.

*a.* **At Neuberg** a wood gas furnace is used, which puddles charges of 3 cwts., and consumes 116 lbs. of pig-iron and 16·5 cubic feet of wood per 100 lbs. of steel.

*b.* **At *Zorge**** **in the Hartz,** white radiated pig-iron and grey charcoal pig-iron are treated in charges of 4 cwts., 2 cwts. of each kind of pig are taken to one charge. In 24 hours from 9 to 11 charges are puddled alternately for steel and wrought-iron, at a loss of 11·68 per cent, and consuming 13 cubic feet of soft charcoal and 11 cubic feet of hard charcoal, weighing together in the dried state 182·17 lbs. per 100 lbs. of blooms. Turf has been experimentally employed, causing a loss of 17·2 per cent of iron and a consumption of 128 lbs. of dried turf per 100 lbs. of blooms.

The steel blooms are re-heated in hollow fires at a loss of 11 or 12 per cent, and a consumption of 1·74 cubic feet of coal per 100 lbs. of product.

At **Kirchhunden**† in Siegen, gases produced with mineral coal are used, which, in comparison with the direct firing, ensure a quicker regulation of the temperature of the furnace, as well as considerably economising fuel; they also cause a greater yield and an acceleration of the process; 8½ charges of 400 lbs. each (¾ white and ¼ mixed pig-iron) = 3400 lbs. are worked off in 12 hours, a result which surpasses those of other steel puddling works. From 35 to 40 per cent is saved in coal, and the loss amounts to 5 or 6 per cent of the charged pig-iron, being 5 or 10 per cent less than that which took place without the employment of these gases.

## BESSEMER'S PROCESS.

The Bessemer process, sometimes termed the *pneumatic* process, treats liquid pig-iron either direct from the iron blast furnace, or re-melted in cupola or reverberatory furnaces in a special apparatus which conducts blast in thin jets into the iron without the application of fuel, as the temperature required is produced by the combustion of the carbon, and also by the oxidation of part of the iron. The carbon contained in the pig-iron is thus so far oxidised that either liquid steel or wrought-iron will result.

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* B. u. h. Ztg., 1863, p. 313.

† Berggeist, 1859, No. 85.

The world is indebted to Mr. Henry Bessemer of Sheffield for this highly valuable process, forming, as it does, a new era in the manufacture of iron. Although it is not based upon essentially new principles, Mr. Bessemer has most ingeniously invented suitable apparatus for the practical application of the process.

Mr. Bessemer first gave publicity to his process in 1856 by reading a paper entitled "The Manufacture of Malleable Iron and Steel without Fuel," before the Mechanical Section of the British Association at Cheltenham. The process, however, was not at that time sufficiently advanced to give satisfactory commercial results. It was generally received with distrust, as, while it employed imperfect means and inferior pig-iron, it was considered impossible to obtain good results. Shinz* removed the doubts which were entertained with regard to the production of a sufficiently high temperature, by burning the carbon alone contained in the pig-iron. Gillon† proved that the high temperature of the Bessemer apparatus originated rather from the oxidation of iron than from the burning carbon, and he asserted that the process caused a great loss of iron and imperfect purification. Pion, Gruner, Sanderson, Truran, and Macadam, who were present at the experiments of Mr. Bessemer, or had opportunity of examining the product, also judged unfavourably of the process. But while the first experiments made in this country yielded a doubtful result, those made in other countries, Sweden excepted, were total failures, owing to the imperfection of the apparatus, &c.

Tunner‡ foresaw the great value of the process at its first starting and advocated it, and Gruner also, later on, changed his opinion. The entire want of confidence on the part of the trade induced Mr. Bessemer to erect a steelworks himself in Sheffield, where he brought the process to its present state of perfection.

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* B. u. h. Ztg., 1857, 7. 17. DINGL., Bd. 142, p. 207.

† B. u. h. Ztg., 1857, p. 378; 1860, p. 36.

‡ LEOB., Jahrb., vi., 258. B. u. h. Ztg., 1859, p. 249; 1862, p. 398.

The iron-masters of Edsken[*] in Sweden meritoriously carried on at the same time this process for its further development. They now produce a very pure wrought-iron fit for the manufacture of thin wire and plates, &c., but this production takes place rather accidentally than intentionally. The resulting iron is frequently burnt (vol. ii., page 706), and contains oxygen; it is, therefore, only useful after a previous deoxidation. Gurlt[†] suggests that iron, after losing its carbon, attains, perhaps, the property of absorbing oxygen like silver and copper; the oxygen then causes red-shortness. On the other hand, it is possible to produce steel of certain qualities with almost perfect security.

According to Tunner's[‡] estimate, there are now 52 converters in operation in England, capable of producing collectively 6000 tons of steel per week. Prussia has 24 converters with a capability of making 1460 tons; France, with 12 converters in operation, can produce 880 tons; in Austria 14 vessels can turn out 650 tons, and Sweden, with 15 vessels, has a productive capability of 530 tons per week. There are two converters at Seraing in Belgium, and two more in Italy, also one or two in Russia, making the total power of production now available for Bessemer steel making in Europe, about 475,000 tons per annum. To this we must add America, with at least 50,000 tons, giving a total of more than half a million tons of steel. The actual production of this present year does not, of course, come up to this figure, but it is, in all probability, considerably above 200,000 tons.

The history of the Bessemer process is elaborately treated by Vicaire.* The following treatises will also be found of great value in the study of the Bessemer process:—

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[*] TUNNER, in Oesterr. Ztschr., 1859, Nos. 13, 26, 30; 1860, Nos. 1, 46. LEOB., Jahrb., ix., 42; x., 201. B. u. h. Ztg., 1859, p. 244; 1860, p. 10; 1861, pp. 91, 294, 399, 479; 1862, pp. 220, 398. MULLER'S Verbesserungsvorschläge. DINGL., Bd. 160, p. 291.

[†] Berggeist, 1860, p. 541.

[‡] Iron and Steel Manufacture, by F. KÖHN, p. 191.

Iron and Steel Manufacture by F. KOHN: London, 1869.

Das Bessemern in Schweden in seiner jetzigen Praxis, von L. E. BOMAN, Hütteningenieur des Schwedischen Gewerken-Vereins Jern Kontoret. Mit einem Vorworte, von P. TUNNER: Leipzig, Felix, 1864, 8vo.

Dass Bessemern in Oesterreich, eine Zusammenstellung, &c., mit geschichtlichen Vorbemerkungen, eingeleitet von OTTO FREIHERRN, von HINGENAU, 8vo: Wien, F. Manz, 1865.

Die Resultate des Bessemerprocesses für die Darstellung von Stahl und Aussichten desselben für die Rheinische und Westphälische Eisen, resp. Stahlindustrie, von Dr. WEDDING, in Preuss. Zeitschrift, 1863, xi., 232.

Bessemer's method adopted in England differs from that used in Sweden in the following points:—

1. In the English process, the pig-iron is previously melted in a reverberatory furnace and sometimes in cupolas, whilst in the Swedish method, the liquid pig-iron is used direct from the blast furnace, but it is seldom made to run direct into the converter. The iron is usually first collected in a ladle and weighed, as this plan admits of an exact fixing of the charge.

The Swedish method is cheaper, as the fuel for re-melting the iron is saved, but it can only be employed with pure pig-iron which is nearly always uniform in quality; as, for instance, charcoal pig-iron and pig from small coke furnaces. On the other hand, the English method is better adapted for impure or non-uniform sorts of pig-iron, as, on re-melting, a purification of the pig-iron, similar to that in the refining process, will take place. This operation also allows of a suitable assorting of the pig-iron, and imparts to the liquid iron such a temperature as the converter requires.

The re-melting of the pig-iron in reverberatory furnaces has this advantage, that the iron comes less into contact with the injurious substances of the fuel; but cupola furnaces have also been employed lately for the purpose of re-melting. The pig-iron used in the steel works at Barrow, is re-melted in Ireland's cupolas. The pressure of blast in the cupolas is about 1 lb. per square inch, and the charges of 7 or 8 tons are melted down with the same coke as is used in the blast furnace. The cupola has been found to be most economical in the making of Bessemer steel, and the quality of the produce is in no way impaired by its use. Mr. Ireland's cupolas were first employed for the Bessemer process in the Mersey Steel and Iron Works at Liverpool. Another cupola, constructed on Woodward's patent, is used at the Manchester Steel and Plant Company's Works, and at the Neuberg Works in Austria, a cupola worked with charcoal was employed for the same purpose, before these works succeeded in working directly from the blast furnaces. At the Barrow Steel Works the spiegeleisen is also melted in a small cupola.

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* Bulletin de la Société de l'industrie Minérale, 1863, viii., 532.

At the same place, experiments were made to work the pig-iron direct from the blast furnaces in the converters. It was found, however, that the quality of the pig-iron is not sufficiently uniform and regular to be at all times relied upon for the Bessemer process, without some further control and rectification, and that, consequently, the quantity of waste or inferior material which was likely to accrue from direct working, would have been more than a balance to any economical advantages which could have been derived from the saving by the re-melting process. The Bessemer pig-iron tapped from the furnaces is, therefore, broken and examined after each pig, and distributed over a large surface into several heaps, so that each single heap does not contain more than half a pig, or about ½ cwt. of iron from one charge. The actual composition of each heap of pig-iron stored in this manner is, therefore, the average of a very large number of castings divided over a lengthened period of working. The occasional productions of irregular, or more or less unsuitable, iron, disappear in such an admixture, and an average quality of pig-iron is obtained, presenting an uniformity of character and a regularity of chemical composition far superior to the unmixed make of any blast furnace, however well and carefully conducted.

2. In Sweden, the process is interrupted as soon as the formation of steel has taken place, which formation may be observed by certain indications, while, in the English method, the pig-iron is totally decarbonised, and steel is formed by the addition of a suitable quantity of spiegeleisen. The former process is cheaper when treating a pure and uniform material, but the uncertainty of being able to stop the process at the right moment has led to a more general adoption of the English method, which, besides, yields a better and purer steel from impure pig-iron. The English method also produces denser castings or ingots, as the combustion of iron is carried on further, thus yielding a higher temperature and a greater liquidity of the metal. It is advisable to melt the spiegeleisen in a different furnace from that used for re-melting the pig-iron.

3. In Sweden, the Bessemer process is conducted in fixed vessels, made of plates of wrought-iron lined with fire-brick, and provided with a spout for filling on one side, with a series of horizontal tuyeres placed in a circle round the bottom, and having a dome-shaped cover and inclined chimney at the top for the exit of gases. The liquid pig-iron is run into this converter through the opening in its side, after the blast is put on, so as to prevent the iron running through the tuyere holes, and the blowing is continued until the whole liquid charge is run out of the converter through the tapping hole. This necessarily introduces an element of uncertainty into the process, which forms one of the most serious objections to the fixed converter. The converters used in the English method may be turned on their axes, thus allowing an easy discharge of the metal; they also allow the blast to be easily shut off, and larger quantities of steel may be kept in them for a greater length of time, without the introduction of air. On the other hand, these movable converters are more difficult to repair, and require a higher pressure of blast, as they contain a higher column of metal than the fixed converters.

The English apparatus and accessories are also more expensive in plant than those used in Sweden, as is proved by the following calculation, made by Wedding for use in Westphalia and the provinces of the Rhine :—

| | Sweden. | | England. | | Sweden. | | England. | |
|---|---|---|---|---|---|---|---|---|
| | £ | s. | £ | s. | £ | s. | £ | s. |
| 2 fixed converters . . | 97 | 10 | — | | | | | |
| 2 movable converters . | — | | 183 | 0 | | | | |
| The pillars supporting the converters, pipes, and tubes, and the mechanism for turning the converters . | — | | 484 | 10 | | | | |
| 1 ladle, including counterpoise and water pressure engine . . | 586 | 0 | 56 | 0 | | | | |
| Total . . . . . . . . . . | | | | | 683 | 10 | 1253 | 10 |
| 1 crane for lifting the moulds and ingots . | 60 | 0 | 60 | 0 | | | | |
| 2 cranes for charging the converters . . | 120 | 0 | — | | | | | |
| 1 accumulator . . . | — | | 225 | 0 | | | | |
| Total : . . . . . . . . . | | | | | 180 | 0 | 285 | 0 |
| 1 steam engine of 60 and 30 horse power respectively . . . | 1200 | 0 | 2310 | 0 | | | | |
| Boiler. . . . . . . . | 315 | 0 | 682 | 10 | | | | |
| Fixtures of the boiler, blast and steam pipes | 97 | 10 | 112 | 10 | | | | |
| Feeding pump, accumulator, and pipes . | 112 | 10 | 281 | 0 | | | | |
| Total . . . . . . . . . . | | | | | 1725 | 0 | 3386 | 0 |
| 2 pairs of reverberatory furnaces . . . . | — | | 900 | 0 | | | | |
| Building and foundation . . . . . . | 300 | 0 | 825 | 0 | | | | |
| Total . . . . . . . . . . | | | | | 300 | 0 | 1725 | 0 |
| Summary. . . . . . . . . | | | | | 2888 | 10 | 6649 | 10 |
| 7 per cent for unforeseen expenses . . | — | | — | | 202 | 10 | 465 | 10 |
| Total cost. . . . . . . . . | | | | | 3091 | 0 | 7115 | 0 |

The cost of the Bessemer plant at the Atlas Works in Sheffield, amounted to £6300.

4. The cost of producing Bessemer steel depends chiefly on the price of the materials, namely, pig-iron, coal, and coke for re-melting the pig-iron, heating the boiler, &c., and refractory materials, and on the price paid for labour. Wedding has calculated the comparative cost per week in Siegen of the English and Swedish methods—

| | *Swedish Method.* 42 charges each of 1171 lbs. raw steel. | | | *English Method.* 30 charges each of 1500 lbs. raw steel. | | |
|---|---|---|---|---|---|---|
| | £ | s. | d. | £ | s. | d. |
| Plant . . . . . . . . | 9 | 5 | 5 | 16 | 10 | 7 |
| Materials. . . . . . | 134 | 4 | 0 | 159 | 17 | 1 |
| Labour . . . . . . . | 9 | 18 | 0 | 11 | 0 | 6 |
| Total . . . . | 153 | 7 | 5 | 187 | 8 | 2 |
| To which must be added 10 per cent for superintendence and unforeseen expenses. . . . . . | 15 | 6 | 9 | 18 | 14 | 10 |
| Total cost . . | 168 | 14 | 2 | 206 | 3 | 0 |

The cost for the production of 49,182 lbs. of steel by the Swedish method amounts, therefore, to £168 14s. 2d., and that for producing 45,000 lbs. by the English method, to £206 3s., or 6s. 10d. and 9s. 1½d. per 100 lbs. respectively.

According to Gruner,* the production of 100 lbs. (Prussian) or 110 lbs. English in the experiments at Woolwich, caused an expense of 6s. 6d., and Bessemer states that the same quantity may be produced for 4s. when the pig-iron is run into the converter direct from the blast furnace. Both statements are perhaps too low, as in this calculation the general cost, &c. is not taken into consideration. Chenot† records the cost of production at the Atlas Works, Sheffield, to be as follows:—100 lbs. Prussian or 110 lbs. English of Bessemer ingots, 8s. 1d.; the steel hammered or rolled into rails, 13s.; the Bessemer steel re-melted in crucibles, 16s. 1d.; and after being rolled or hammered, £1 1s. 1d.

Wedding's calculation proves that the English method is more expensive than the Swedish, but, nevertheless, it is to be preferred in most cases, as it works with greater certainty of success, and may even be employed with less pure pig-iron than that required by the Swedish method.

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* B. u. h. Ztg., 1861, p. 477.

† Ibid., 1863, p. 425.

According to Fremy,* two converters capable of working charges of 3 tons, are equivalent to six or seven refinery fires, nine puddling furnaces working 24 hours, and 300 crucibles, in the melting of steel. The consumption of fuel amounts to scarcely one-eighteenth of the weight of the product, while in the other methods it is six or seven times as large.

At Turracht† in Styria, the English and Swedish methods are combined in such a manner that the liquid pig-iron is run direct from the blast furnaces into movable converters. Whilst three or four men produced from 32 to 40 cwts. of raw steel in a week by the finery process with a consumption of 30 or 40 cubic feet of charcoal per cwt., the Bessemer converter now treats 25 cwts. of pig-iron in 20 minutes with scarcely any fuel.

**The Chemical Reactions in the Bessemer Process.**—The process requires the blast to be introduced under a sufficient pressure, which varies with the liquid column of iron in the converter. This column, in the English converters, is from 12 to 14 inches deep. This depth is not exceeded in the converters of larger size, as they have a larger diameter and a greater number of tuyeres in proportion, so as to hold more metal without increasing the depth of the ferrostatic column. The blast pressure varies in the English converter from 12 to 25 lbs. on the square inch, and 6 to 8 lbs. in the Swedish converter, and it is never less than three times as great as the weight of the liquid column which rests upon the tuyeres. This shows that the resistance caused by the liquid column bears only a comparatively small proportion to the entire resistance presented to the passage of the blast through the Bessemer apparatus.

In Sweden, 396 cubic feet of blast per 100 lbs. of pig-iron are required, and in England, about 500 cubic feet; a most perfect distribution of the blast in the liquid iron must be aimed at. A very high temperature will then be produced by the combustion of the carbon and of some of the iron, which, however, is lowered again more or less by the products of combustion and the slag, which absorb some heat, and also by irradiation, which varies with the proportion of the melted iron to the surface of the vessel, &c. The excess of temperature required for keeping steel and wrought-iron in a liquid state, amounts, according to Gruner's calculation, to about 1233°, a higher temperature is therefore produced than is required for keeping wrought-iron liquid, the melting point of which is between 1800° and 2000° C., liquid pig-iron having a temperature of 1600° or 1700° C. The specified difference of temperature exercises an important influence on the largeness of the charges, which may be of any weight between 1 and 10 tons; those varying from 3 to 5 tons are most commonly used, while in Sweden they are, on an average, 2 tons, and were formerly only from 15 to 22 cwts.

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* B. u. h. Ztg., 1863, p. 359.

† Oesterr. Ztschr., 1864, Nos. 2, 3.

Hot blast has been experimentally employed in Sweden without producing the high temperature required, probably owing to the less amount of oxygen which was introduced in the same time, but it is natural to suppose that hot blast will facilitate the process if introduced in a sufficient quantity.

The pig-iron to be charged should be melted rapidly, and at the highest temperature which can be produced. The gutters through which the iron passes into the converter must be of large sectional area, and carefully dried and heated previous to tapping. The converter must have a full white heat before receiving the charge, and the liquid iron must be run into it as rapidly as is compatible with safety and cleanliness. The converter should never be turned up before the safety valve upon the air vessel has commenced to blow off, and the blast is let on full before the converter is brought into an upright position.

The process is judged* chiefly by the appearance of smoke, flame, and sparks, which are emitted from the apparatus, and accordingly, the process may be divided into three periods, which, however, are not always clearly perceptible.

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* Leob., Jahrb., vi., 256; ix., 41; x., 201; xii., 126. Bericht über die zweite Versammlung der Berg-und Hüttenmänner in Wien, 1862, p. 65. Dingl., Bd. 160, p. 291. Berggeist, 1860, p. 564. B. u. h. Ztg., 1862, p. 68; 1863, p. 355. Ann. d. Min., 1863, livr. 5. Wanganheim, der Bessemer process: Weimar, 1863.

**The First Period**, also designated the refining period, or that for the formation of slag, is characterised by a slightly luminous dark reddish-brown or yellow flame, a thin smoke, with a good many scintillating sparks of burning iron. As in the refining process, iron and silicon are first oxidised, owing to the affinity of protoxide of iron to silica. Manganese oxidises at the same time, partly direct, and partly by the reaction of the peroxide of iron; protoxide of manganese is thus formed, which, being a strong base, facilitates the removal of silicon. The slag formed also enters into combination with the silica of the lining of the apparatus, and becomes more and more basic and rich in magnetic oxide. The graphitic carbon is transformed into chemically combined carbon; only a small part of it burns, forming first carbonic oxide and then carbonic acid, and the flame of carbonic oxide gas colours the escaping flame yellow, owing to the surplus of atmospheric air which it contains. This period occupies about 4 or 6 minutes. A high temperature is produced at this stage of the process chiefly by the combustion of iron, and this temperature is retained in the product of combustion (oxidised iron), whilst carbonic oxide is formed in the following period. The temperature rises again in the last period, owing to the combustion of iron.

The length of the first period depends entirely on the size of the charge, and the amount of graphite and silicon contained in the pig-iron, as is proved by the following analyses of different kinds of Swedish pig-iron, made by Boman :—

| | | | | |
|---|---|---|---|---|
| Graphite . . . . . . | 4·10 | 4·00 | 3·95 | 3·900 |
| Chemically combined carbon . . . . . . | 0·27 | 0·42 | 0·48 | 0·600 |
| Silicon . . . . . . . | 1·74 | 1·34 | 0·94 | 0·950 |
| Manganese . . . . . | 0·28 | 0·22 | 0·49 | 0·216 |
| Calcium . . . . . . . | — | — | — | 0·244 |
| Magnesium. . . . . | — | — | — | trace |
| Aluminium . . . . . | — | — | — | — |
| Iron . . . . . . . . . | — | — | — | 93·660 |
| Copper . . . . . . . | — | — | — | 0·005 |
| Phosphorus . . . . | — | — | — | 0·018 |
| Sulphur . . . . . . . | — | — | — | 0·020 |

| | | | | |
|---|---|---|---|---|
| Number of the hardness of the pig-iron | 1·5 | 1·5 | 1·5 | 2·0 |
| Amount of the charges . . . . . cwts. | 31 | 34 | 41 | 34 |
| Time for the formation of slag . minutes | 8·5 | 8·5 | 2·5 | 1·0 |

**The Second or Boiling Period** is characterised by the fact of the metal bath, which is intimately mixed with the basic slag, rising and foaming vigorously, owing to the evolution of gas; the slag oxidises the carbon, and the iron thus reduced becomes again oxidised by the action of the blast. As a far more considerable evolution of gas (carbonic oxide and atmospheric nitrogen) takes place than in the first period, small portions of liquid masses, chiefly of slag, are thrown out, slightly exploding, the shower of sparks of burning iron decreases, and the flame assumes a blue colour for the reason that less iron is burnt, and carbonic oxide gas burns with a blue flame. This lasts for about 6 or 8 minutes, when

**The Third Period** commences. The carbon which still remains is now mostly oxidised to carbonic acid, by the action of the blast and by the slag, which has become more acid. In the Swedish method, the more or less perfect removal of the carbon depends on whether the production of hard or soft steel is desired, which will hereafter be described more at length. In the English method, the decarbonisation is continued until the last trace of carbon is burnt away. The flame is less luminous, and gives the characteristic bluish violet of carbonic oxide, containing now and then other colours, chiefly green and blue. The flame is intensely hot. The eruptions gradually cease, and the shower of sparks increases again, owing to a combustion of iron. Malleable wrought-iron has now been formed, and so high a temperature is produced, that it is capable of keeping the wrought-iron liquid for some time. This high temperature is due to the fact that the heat produced is no longer absorbed by oxidation and formation of carbonic oxide, which is the case in the second period. The wrought-iron is more thinly liquid than steel, but it is more liable to solidify. When the flame disappears entirely, and only a stream of clear luminous gas from the interior is emitted from the apparatus, whilst the melting mass within has settled down, all the carbon is removed, and the oxygen of the atmospheric air oxidises the iron, transforming it into the state of coarse crystalline burnt iron. This very pure product is red-short, owing either to its crystalline texture, or, according to Fremy, to the presence of nitrogen, or perhaps to the absorption of oxygen, but it may be rendered malleable by heating it under a cover of coal, thus forming the purest and softest iron which can be produced metallurgically. An addition of spiegeleisen will convert burnt iron into steel.

The purpose and intention of the final addition of spiegeleisen* (about 10 per cent) is to remove the excess of oxygen. The elements by which we can effect this removal are carbon, silicon, and manganese. Of these, silicon has one important advantage, namely, that it forms no gaseous combination with oxygen, and therefore causes no ebullition in the ladle or in the moulds. There is, however, a great danger of overcharging the steel with the silicon, and by so doing, causing it to be brittle, hard, and slightly elastic. Carbon and manganese form gaseous combinations with oxygen at the high temperature existing in the converter, the ebullition in the ladle and moulds, therefore, is not easily avoided when these elements are used for removing the oxygen, but the excess of carbon gives the required hardness to the steel, and any surplus of manganese remaining in the steel is comparatively harmless as regards the quality of the product. When silicon is present, the manganese is less liable to cause ebullition, since it can form a liquid slag. For these reasons, the final addition to the Bessemer charge should contain the three elements, carbon, silicon, and manganese. To allow for the uncertainty of the quantity of oxygen left in each charge, there should be a surplus of manganese, but no more silicon than is required to form a slag with the greater portion of the oxide of manganese, and only sufficient carbon for the final carbonisation of the charge of steel. The natural spiegeleisen is, as a rule, too poor in manganese and too rich in carbon to produce this effect; and consequently, when steel is made by its application, it is difficult to produce a very soft quality. Mr. Henderson's ferro-manganese, which contains from 20 to 30 per cent of manganese, with 5 per cent of carbon, and a small quantity of silicon, is a substance of much greater value in the production of the highest qualities of soft steel; and from the manner in which these artificial alloys are manufactured, it is possible to bring the relative quantities of the elements to almost any desired proportion.

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* Kōhn, Manufacture of Iron and Steel, p. 83.

The spiegeliesen should not be kept in the furnace for any length of time, or it will lose its manganese and silicon by oxidation. It should run into the converter very quickly, so as to enter the liquid charge with a certain momentum. This prevents its collecting upon the surface of the decarbonised iron, which has a greater specific gravity than spiegeleisen or ferro-manganese. After the final addition, it is not necessary to turn up the converter a second time, since an immediate reaction takes place; and although the blast is entirely shut off, a large white flame rushes out of the converter.

This last period occupies about 5 or 6 minutes, therefore the whole process, with a charge of from 1 to 3 tons, only lasts from 15 to 20 minutes.

This rapidity is due to the uniform and intimate contact of the air with the iron at high temperatures, and also to the absence of fuel, which, in the finery process, lessens the oxidising reaction of the air and the slags. In the puddling process, the oxidation is not so rapid as in the Bessemer process, because the masses in the puddling furnace are at a lower degree of liquidity, and the temperature of the furnace is not so high.

After the liquid steel has been mixed with spiegeleisen, it is, in most cases, immediately poured into the ladle. An exception is, however, made when no flame is visible at the mouth of the converter, after the addition of spiegeleisen or ferro-manganese; in this case, the vessel must be turned up a second time, and the blast passed through it for a few seconds. This is done because the absence of a vivid reaction indicates that the charge had not been blown long enough in the first instance, causing no surplus of oxygen to be left in it, and the additional time of blowing is therefore required for the removal of the excess of deoxidising elements added at the end of the charge.

The moulds are arranged on the floor of the casting pit in a semi-circle round the ladle, which is raised to a sufficient height to clear the top of the moulds, and is turned so as to bring the hole over the centre of each successively; the plug is lifted, and the molten steel flows out in a stream about an inch in thickness. Care must be taken to prevent the stream from striking against the side of the mould, as, in this case, the ingot is likely to be unsound. When the mould is filled, a small quantity of sand is thrown on the surface of the metal, which is then covered by a piece of thin sheet-iron, and the whole is secured by a cross bar, passing through two eyes on the top of the mould.

The most important, and at the same time, the most difficult part in the management of a Bessemer charge, is the determination of the precise moment when the charge is completed, and when the vessel must be turned down to receive the final dose of spiegeleisen. When the flame is clearly visible at the end of the charge, there is no difficulty, after a little experience, in recognising a sudden change in its colour and appearance; but some qualities of iron evolve such masses of dense smoke, red, white, brown, or yellow in colour, that the flame is completely covered, and it is not easy to ascertain when the change takes place. The spectroscope, the slag test, and other similar appliances (which will be described when treating of the Swedish method) are then brought into requisition with more or less success; but fortunately these troublesome kinds of iron form the exception, and not the rule, with the pig-iron used in the Bessemer process.

Another important point is the proper management of the blast, and many of the first experiments failed because either too little blast or blast of too low pressure was employed.

After the converter is charged, the blast must be admitted before it is turned back to the vertical position, otherwise the molten metal will run down through the tuyeres. A pressure of 5 or 6 lbs. per square inch is required to overcome the hydraulic head of the liquid column of metal, and from 9 to 14 lbs. more, to force the air through with the proper velocity, or from 15 to 20 or 25 lbs. per square inch total pressure.

Now the resistance which the blast must overcome[*] in passing through the converter, is composed first, of the friction in the pipes and passages between the vessel and the tuyere box; secondly, of the friction and resistance caused by the many narrow holes of the tuyeres; thirdly, of the head of liquid column covering the tuyeres, and the friction within the liquid metal; and fourthly, of the friction and resistance caused by the contracted mouth of the converter. The sum total of the resistances offered to the blast in passing through the vessel, is measured by the pressure guage on the platform; and it is therefore obvious that the variations of pressure, as indicated by the guage, do not of themselves show to what cause any particular item is due. The burning or shortening of the tuyeres may lessen the friction, or the partial choking reduce the area of passage; the iron may become more or less fluid; the throat may be partly filled with slag, and thereby reduced in area, or a leak in the pipes may cause a less pressure of air; all these and many other causes, which, by their simultaneous action, interfere with each other's individual effects upon the pressure guage, make the indication of that instrument somewhat confused and difficult to understand. It is better, therefore, in controlling the blast pressure during the process, to observe the behaviour of the converter rather than the indications of the pressure guage. The speed of the gaseous current must be so great, that the flame which rushes out of the converter maintains a clear and well-defined outline and a steady position. If the flame begins to waver or oscillate laterally, it is always considered a sign of insufficient blast pressure. An excess of blast pressure is attended with violent and very voluminous eruptions of slag and metal from the vessel; this can be easily remedied by allowing a portion of the blast to escape from the main pipe. This means is preferable to throttling, because it does not throw any sudden back pressure upon the blowing engine, and allows the latter to maintain a uniform speed.

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[*] KÖHN, Manufacture of Iron and Steel, p. 82.

An accident which occasionally happens, is the cracking of a tuyere. If this takes place during the earlier part of the process, the vessel may with safety be turned down, and the metal will remain fluid while a fresh tuyere is inserted. If the accident happens during the later stage of the process, the danger of setting or solidifying is much greater, but with skilful management there is still a possibility of saving the charge. The vessel is turned down for a second, and this allows the liquid steel, which fills the crevices of the cracked tuyere, to solidify and choke the escape passage or leak. The vessel is thereby rendered tight for a few moments, after which time the process may be repeated. It is possible for such an operation to be renewed three or four times, and the few fractions of minutes thus gained may be sufficient to complete the conversion of the charge.

The most important question is the selection of the pig-iron, as injurious substances contained in the pig, chiefly sulphur and phosphorus, cannot be removed in the Bessemer process, owing to the rapidity of the operation and the higher temperature at which it is carried on, as well as the impossibility of tapping off the slags which have received the greater part of the impurities. Phosphate of iron and manganese which has been formed, is reduced at the high temperature by metallic iron, and the phosphorus combines again with the iron ; a small portion of the sulphur is transformed into sulphurous acid, but is immediately decomposed again by metallic iron ; the greater part of the sulphur enters the slag as a sulpho-silicate, from which it is again taken by the iron. The sulphur is more perfectly removed in the English than in the Swedish process, because, by the addition of spiegeleisen, it is distributed into a greater mass, and part of it is separated by manganese.

The percentages of the impurities of pig-iron, namely, silicon, carbon, manganese, sulphur, phosphorus, and copper, must all correspond to certain figures, ascertained by experience, or must, at least, remain within certain limits, in order to insure a complete trustworthiness and regularity of practice, with the production of a high quality of metal.

Sulphur, phosphorus, and copper must also be limited to the extremely small percentage of 0·05, whenever a high quality of metal is to be produced, as the amount of neither of these ingredients is sensibly reduced by the process. However, the influence of phosphorus on steel requires further investigation, as no exact percentage is known within which phosphorus is harmless. We may expect valuable information on this subject from the trials with Heaton's patent process, which are now being carried on. Opinions also differ as to the influence of sulphur in the Bessemer process. Whilst Bessemer considers 0·1 per cent of sulphur in the pig-iron to be too much, Tunner considers that Styrian pig-iron with 0·2 per cent of sulphur is still applicable, because sulphur in small quantities does less injury to the quality of steel than to that of wrought-iron; for this reason, some sorts of coke pig-iron, which mostly contain sulphur, yield a useful product in the Bessemer process, the more so as the presence of manganese improves iron or steel containing sulphur, but not such as contain phosphorus. Experiments made at Turrach with more impure iron than that of the other Styrian iron works have confirmed this view, as the impure iron yielded a good steel, but inferior wrought-iron.

Boman states that 0·015 per cent of sulphur may be removed in the Bessemer process, if the pig-iron is otherwise suitable.

According to Wedding, a small amount of silicon, 1 or 1½ per cent, facilitates the development of heat in the first period of the process, as the silicon burns, whilst the silica taken from the furnace lining or slag which may be present, absorbs temperature; silicon also facilitates the formation of slag, owing to its uniform distribution in the liquid iron. A very large amount of silicon, such as is contained in the darkish grey pig-iron, produced at very high temperature, gives rise to the formation of a siliceous, hard, red-short steel, and to a greater loss of metal. According to Bessemer, the percentage of silicon should not be below 1 per cent, or above 2 per cent.

A certain amount of aluminium is, according to Gruner and Lan, more injurious than is generally believed, and it appears that, for this reason, the iron ores from Dannemora, which are poor in alumina, form an excellent material for the Bessemer process.

In this process, manganese exerts a favourable influence, as it does also in the other methods of producing steel (page 32), and its chief effect is to protract the first period, in which, by the oxidation of silicon, manganese, and chiefly of iron, and previous to the burning of carbon, so high a temperature is developed as to keep the mass liquid in the second period, during which the temperature is lowered by the formation of carbonic oxide.

Graphitic carbon acts like manganese, protracting the first period, as, before it oxidises, the greater part of it requires to be transformed into chemically combined carbon. If white pig-iron, which only contains chemically combined carbon, is treated, the second period of the process will commence at once, as is proved by the experiments made at Edsken. The carbon oxidises, and the temperature produced is not sufficiently high to keep the mass liquid. A thickly liquid steel intermixed with slag will result, and the ingots will be coated with oxide and covered with dull blisters; such steel cannot be condensed by hammering.

The best materials for the Bessemer process, as proved by experience, are the good grey sorts of pig-iron free from sulphur and phosphorus, and if coke and charcoal pig-iron are equally pure, the former is to be preferred, as its graphite is transformed into chemically combined carbon with greater difficulty than that of charcoal iron, thus causing the first period to be protracted.

Köhn considers the distinction made between combined and uncombined or graphitic carbon, when judging of the applicability of pig-iron for the Bessemer process, to be a prejudice; and he may possibly be right, and the quantity of carbon contained in the pig-iron, may be of greater importance than the state of combination.

The same author states in his valuable book, which we have before mentioned, and which has furnished us with many details in our description of the Bessemer process, that the percentage of carbon ought to be as high as possible, and should never be below 3 per cent. Concerning the quality of pig-iron required, he furthermore makes the following statement:—To a certain extent, the presence of manganese replaces that of carbon, but the pig-iron charges should not contain more than 3 per cent of manganese, because the great affinity of this substance for oxygen causes a violent action in the converter, resembling a series of explosions, by which a great quantity of metal is thrown out. Silicon counteracts this violent action of manganese, and a charge of manganiferous pig-iron, mixed with a suitable proportion of pig-iron containing about 3 or 3·5 per cent of silicon, works quietly and yields an excellent product. In a similar manner it is very advantageous, in making up the charge for the converter, to mix pig-iron which is overcharged with silicon with a proportionate quantity of spiegeleisen. The charge requires at least 2 per cent of manganese for each per cent of silicon that it holds in excess of the requisite quantity, say 1½ per cent. When the pig-iron is melted in an air furnace, the percentage of carbon, silicon, and manganese are sensibly diminished by the ordinary influence of the flame. This effect, to a certain extent, depends on the management of the melting furnace, and the attention of the operator should be directed to the prevention of an excessive oxidation in the air furnace. When a cupola is used for melting the pig-iron, or when the pig-iron is run direct from the blast furnace into the converter, the proportionate quantities of carbon, silicon, and manganese named above, may be slightly reduced.

The iron most preferred in Sweden, is produced from roasted ores and highly basic mixtures at very high temperatures. On tapping, the pig-iron flows with a white colour without sparkling, and is run into slightly warmed iron moulds 1 inch thick. When cool, it perhaps shows a very small stripe of white iron. About 15 per cent more coal is consumed in the production of this iron for the Bessemer process, than in the production of common white forge iron. The masses which are thrown out of the converter, containing about 90 per cent of pig-iron, are gradually added to the ore mixture in small quantities.

The best English pig-iron that can be used in the Bessemer process is that smelted from Cumberland hæmatite, about No. 1 or 2 in greyness. According to Bauerman, it should contain from 1½ to 2 per cent of silicon as a minimum, and not more than 0·2 per cent of phosphorus.

According to Jordan, the pig-iron for the Bessemer process at Essen in Westphalia, is produced from mixtures of spathic ore and hæmatite, and should contain of foreign matters—

| | | per cent. |
|---|---|---|
| Manganese . . . . . . . | maximum | 1·00 |
| Sulphur . . . . . . . . | ,, | 0·04 |
| Phosphorus . . . . . . . | ,, | 0·06 |
| Carbon. . . . . . . . . | minimum | 5·00 |
| Silicon . . . . . . . . | ,, | 2·00 |

The following complete series of analyses, taken at different stages of the Bessemer process, will be found interesting. It refers to the Austrian Government Works at Neuberg in Styria. The pig-iron operated on was smelted from the spathic ores of the Erzberg with charcoal:—

*Analyses of Metal.*

| | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|
| Carbon, graphitic . . | 3·180 | — | — | — | — |
| Carbon, combined . . | 0·750 | 2·465 | 0·949 | 0·087 | 0·234 |
| Silicon . . . . . . . | 1·960 | 0·443 | 0·112 | 0·028 | 0·033 |
| Phosphorus . . . . | 0·040 | 0·040 | 0·045 | 0·045 | 0·044 |
| Sulphur . . . . . . | 0·018 | trace | trace | trace | trace |
| Manganese . . . . | 3·460 | 1·645 | 0·429 | 0·113 | 0·139 |
| Copper. . . . . . . | 0·085 | 0·091 | 0·095 | 0·120 | 0·105 |

No. 1, original pig-iron.
No. 2, metal taken at the end of the first period.
No. 3, metal taken after the boil.
No. 4, metal taken at end of blowing.
No. 5, metal restored to steel by addition of pig-iron.

*Composition of Slags.*

| | II. | III. | IV. | V. |
|---|---|---|---|---|
| Silica . . . . . . . . . | 46·78 | 51·75 | 46·75 | 47·27 |
| Alumina . . . . . . . . | 4·65 | 2·98 | 2·80 | 3·45 |
| Protoxide of iron . . . | 6·78 | 5·50 | 16·86 | 15·43 |
| Protoxide of manganese . | 37·00 | 37·90 | 32·23 | 31·89 |

*Composition of Slags (continued).*

| | II. | III. | IV. | V. |
|---|---|---|---|---|
| Lime | 2·98 | 1·76 | 1·19 | 1·23 |
| Magnesia | 1·53 | 0·45 | 0·52 | 0·61 |
| Potash<br>Soda | traces throughout | | | |
| Sulphur | 0·04 | trace | trace | trace |
| Phosphorus | 0·03 | 0·02 | 0·01 | 0·01 |

These analyses are numbered to correspond with those of the metal taken at the same time.

The ingots are removed from the moulds while still red-hot, but they cannot be rolled immediately, as they are too hot inside and not strong enough to be drawn out. They are, therefore, either allowed to cool or are placed in a heating furnace, which keeps the outside of the ingots sufficiently warm, whilst the inside becomes gradually cooled to the temperature required for rolling, &c.

Apparatus for handling heavy ingots are patented by Mr. John Ramsbottom, of Crewe, and are described in F. Köhn's "Iron and Steel Manufacture."

The ingots are liable to have the following defects:—

*a.* Cracks lengthwise; these, however, seldom occur, and, according to Boman, they originate from a defect in the moulds, which prevents a uniform contraction of the ingots in cooling (page 122).

*b.* Cracks occur crosswise on the upper part of the ingot, if liquid metal runs out after the mould is closed, the contraction of the upper part while solidifying being thus impeded.

*c.* Cracks on the bottom occur in consequence of the great pressure which the liquid mass, in the interior of the ingot, exerts upon the lower parts of the ingot which first solidify. These cracks may be prevented by placing the moulds immediately after casting in a nearly horizontal position, so that their upper part is only slightly elevated above the lower part.

*d.* Soft steel is generally porous at the edges when cast in narrow moulds at a very high temperature, whilst the liquid steel is running in a large stream. The reasons for this require further explanation, and the different opinions held as to this behaviour of steel, will be given when we treat of cast-steel.

The holes in such steel have sometimes a silver-white surface, and are therefore free from oxide; an ingot of this kind will become perfectly dense when forged at the right temperature, and will be uniform after being drawn out under the hammer or rolls; it does not, however, attain so fine a grain as cast-steel. These holes are more numerous in the centre of the ingots, whilst a second kind, generally prevailing in the vicinity of the outer surface, are coated with a film of oxide; and steel in which tarnished holes occur cannot be rendered uniform by forging. It is assumed that the film of oxide is due to the action of free oxygen, inclosed in the bubble at the time of its formation.

Great improvements have been made in the production of ingots free from blister and slag, as for instance, the shutting off of the blast immediately after conclusion of the process, the cooling of the over-heated steel to a certain degree before casting, and the casting of ingots from the bottom, &c.

The texture of these ingots, however, is always loose, and requires to be condensed by a strong hammering.

When castings are being formed, the contraction must be taken into consideration on making the moulds; this contraction of Bessemer iron and soft steel is 2·5 per cent.

The product of the Bessemer process sometimes breaks suddenly when bent on an anvil at a temperature a little above red-heat; but it behaves like good iron or steel when treated at a higher or lower temperature. It is chiefly Bessemer iron, containing 0·4 per cent or less of carbon, that has this deficiency; it is then usually called burnt. An addition of 1 per cent of fused spiegeleisen to the ladle which contains the burnt iron, will improve its quality.

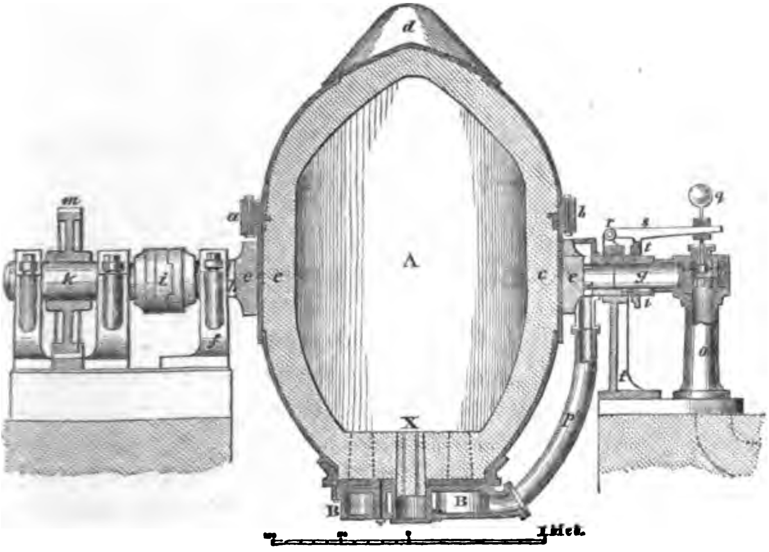
## The English Method of Conducting the Bessemer Process.

The following apparatus are required for this method:—

**1. Bessemer Furnace or Converter.**—Bessemer, after having employed various movable and fixed vessels, has, at last, adopted a movable egg- or pear-shaped vessel, suspended on trunnions, and provided with appropriate machinery, whereby it may be rotated vertically, through an angle of about 180°. The outer casing is made of wrought-iron plates riveted together, and, in its original form, was not unlike a soda-water bottle, supposing the pointed end to be flattened, and the neck turned over at an angle of about 30° to the body. In the more recent forms, however, especially those intended for working with large charges, increased capacity is obtained by making the body and lower part cylindrical.

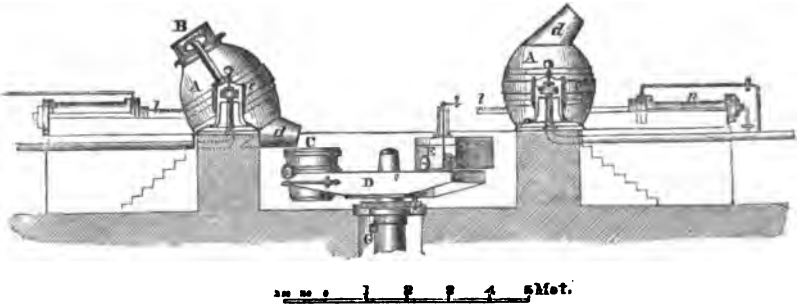
The new apparatus used at Seurin de l'Isle in France is represented by Figs. 10 to 14.

FIG. 10.



The converting vessel, A, consists of two parts, which are united by screw bolts at *a* and *b*, and can be separated for convenience in lining. In some of the more modern designs this joint has been discarded, and replaced by one at the bottom of the vessel, which allows the entire bottom of the converter, with its tuyeres and tuyere-box, to be removed, whilst the rest of the vessel remains intact. The interior lining, *c*, of the converter must be made of the most refractory material that can be obtained. Fire-brick, clay, or sand may be used; but in Sheffield, and in England generally, an almost pure siliceous sandstone from below the coal measures, known as *ganister*, is found to be better adapted for this purpose than any other substance. It is ground to a fine powder, and may either be used alone or mixed with a certain proportion of powdered fire-brick; in either case, a small quantity of water is used, sufficient to make the powder slightly adhesive; it is then tightly rammed between the inside of the shell and the wooden core, which is afterwards removed. The neck, *d*, is usually lined with fire-bricks. The flame, &c., emitted from the neck of the converter, is conducted into a chimney by a wrought-iron hood.

FIG. 11.



The suspension of the converter is effected by means of a stout hoop of wrought-iron or steel, *e*, carrying two trunnions, *g* and *h*, which is shrunk on to the body of the converter at the widest part. In the Atlas Works, Glasgow, the hoop or belt and trunnions, are of cast-iron, and are made in two parts, which are held together by bolts. This is more economical than a belt of wrought-iron upon which the two trunnions are forged; but the latter mode of construction reduces the dimensions and weight of the belt and trunnions, and is a better guarantee against accidents. Cast-iron has, however, been proved by experience to be fully reliable for the purpose in question. The trunnions are supported by the cast-iron standards, *f*, *f*. One of the trunnions is hollow, forming a passage for the blast, while the other is solid and connected by the coupling box, *i*, with the pinion, *m*, by means of which the converter can be turned on its bearings, *f*, *f*, by the hydraulic cylinder, *n*, and the toothed rack, *l*. The water pressure engine possesses a double action, the valve being worked by hand gear placed at a distance. In most cases, the trunnion is directly connected with the pinion, having no coupling box between.

FIG. 12.

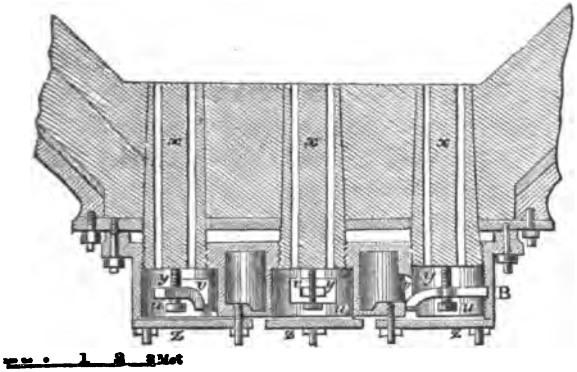
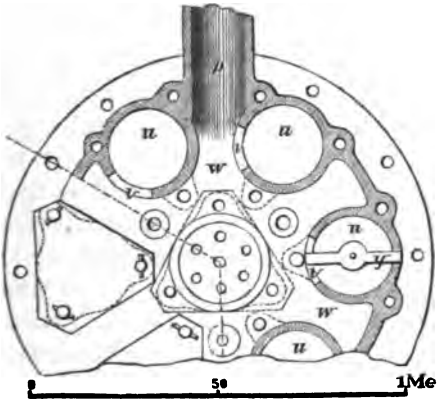


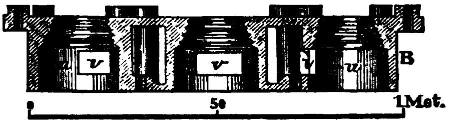
FIG. 13.



The blast from the main enters the hollow trunnion, *g*, by means of the vertical tube, *o*, and is conducted into the wind-box, B, through the tube, *p'*. In order to regulate the admission of blast, the tube, *o*, is provided with the valve, *p*, which is usually pressed down by the weight, *q*, and thus closed. This weighted valve is connected with a lever, *s*, supported by the disc-shaped cam, *t*. The cam is so arranged that the air passage is opened before the vessel arrives at its upright or vertical position, and the blast is shut off when the vessel is tipped or turned down (Fig. 11, on the left-hand side).

The bottom of the converter is, in all cases, flat, and made of wrought-iron; it contains seven circular holes for the insertion of the tuyeres. The tuyere box, which is a cylindrical chamber, is fastened to the bottom of the converter; it contains seven cylindrical compartments, *u*, communicating with the reservoir, *w*, by means of the lateral openings, *v*. The reservoir, *w*, is connected with the blast-pipe, *p′*. The compartments, *u*, correspond with the circular holes in the bottom of the converter, and receive the tuyeres, which are cylindrical or slightly tapered, and made of fire-clay, each perforated by twelve parallel holes, of 1 centimetre in diameter. These perforations, to ensure facility in moulding, are cylindrical near the top or front, and slightly tapered at the back. The size and number of the tuyere holes, has been a subject of much attentive consideration. Large tuyere holes involve a waste of air blown through the vessel, and a reduction of the temperature; whilst small holes increase the friction, and necessitate a greater blast pressure in the tuyere-box, and at the same time, are more liable to choke. Experience has fixed the size of the tuyere holes from $\frac{3}{8}$ to $\frac{1}{2}$ an inch in diameter. The length of the tuyeres is equal to the thickness of the lining at the bottom of the converter; they are never allowed to project beyond the ganister lining, but they become shorter after each charge, and must be removed when they have decreased more

FIG. 14.



than 3 or 4 inches. The tuyeres are kept in position by the screws, *y*, and the compartments, *u*, are closed by the plate, *z*, which is screwed on.

The tuyere-box of an apparatus in Sheffield, capable of holding 1 or 1½ tons of iron, contained seven tuyeres, with five holes, each ¾ of an inch in diameter; the Atlas Works have converters capable of containing 5 tons of iron, with seven tuyeres, each of which has seven holes of ⅜ of an inch in diameter. The tuyere-box is sometimes provided with three wheels for its removal, when it is replaced by a box of similar construction*.

A Bessemer steel works has usually two converters, placed opposite to each other, with a deep cylindrical casting pit between them (Fig. 11). In the centre of the pit, another water pressure engine, G, with a vertical cylinder and solid plunger piston, is fixed, having at its upper end a cross-bar, D, formed of two parallel girders strongly braced together, to one end of which is attached the ladle, C, the overhanging weight being supported by a counterpoise on the opposite end. The counterpoise, F, is provided with a crank, by means of which it may be moved to and fro as the ladle is full or empty. This ladle is movable on its axis. In order to move it round the central pillar, so as to bring it over each of the moulds in succession, the top platform is provided with spur gearing, so that it revolves like a railway turn-table. The motion is regulated by a man who stands on the platform, and who also directs another movement for reversing the ladle on its bearings from time to time, in order to remove the waste after the end of the cast. The valve of the central engine, which raises and lowers the ladle, is in charge of the same man who works the tipping engines for the converters. He is usually stationed at one side of the converting house, in a box sufficiently elevated to command a clear view of the whole of the apparatus. The working power of the engines is obtained from a small steam engine, driving the necessary force pumps, which deliver their supply into two accumulators for equalising the pressure.

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* Mining and Smelting Magazine, iv., 231.

The ladle which receives the metal from the converter, and which is fixed to the cross-bar, D, is provided at the bottom with the tapping-hole, *a*, as is shown by Figs. 15 and 16, representing the ladle. This hole may be closed by a conical plug or stopper, *b*, made either of fire-clay or of wrought-iron coated with clay, attached to the lever, *e*, by means of which it can be lifted from the outside, and in this manner the liquid metal is cast from the bottom, avoiding the introduction of slags or other impurities into the ingot moulds. The ladles are made of strong boiler plate.

FIG. 15.

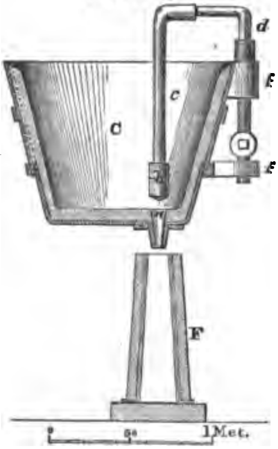
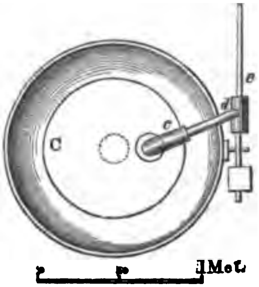


FIG. 16.



The ingot moulds F (Fig. 15), are of cast-iron, and are occasionally provided with wrought-iron hoops. They are 2 inches thick, from 3½ to 4½ feet high, and usually rectangular in horizontal section, tapering from the bottom to the top, so as to measure from 8 to 17 inches at the top, and from 9 to 18 inches at the bottom. The moulds are open on both sides, and stand either on a cast-iron plate or on blocks made of fire-clay and ganister. Before being used, they are painted with graphite or smoked to prevent adhesion.

Round moulds are also frequently used, and are said to be less liable to crack. This is only the case when they are compared with carelessly constructed square or rectangular ingot moulds, the sides of which are occasionally slightly concave in form. Such a form inevitably causes the ingot or mould to crack during the process of cooling, as the contraction of the ingot is then opposed by the wedging action of the sides of the mould. This kind of convexity may even be produced by unequal expansion in a mould which is straight, or nearly so, when quite cold; and it is, therefore, advisable for all ingots to be made slightly convex. The cracking of ingots and moulds will thus be easily avoided, without recourse being had to circular moulds and round ingots, which are inconvenient to forge.

Ladles of similar construction are used for charging the converter with liquid pig-iron, where the melting furnaces stand on the level of the converters, but those furnaces are usually on a higher level, and the liquid iron is run into the converters by means of gutters made of wrought-iron, lined with clay or sand. They swing round a central pivot, so as to be put out of the way, or brought into the proper position when the converter is turned down and ready to receive the charge of liquid iron.

The proportion or size of the opening or throat of the converter, is a very important point. The volume of gas which passes through the throat is, probably, on account of the high temperature, ten times as great as the volume of cold air which passes through the tuyeres. It is necessary to make ample provision for the ready escape of these gases, as it is not desirable to create a back pressure against the blast. On the other hand, the throat of the converter should not be wider than necessary, since the radiation of heat from the interior increases with the size of the opening, and the temperature of the charge is thereby injuriously affected.

As the tuyeres in the Bessemer apparatus are quickly wasted and difficult to replace, Fairbairn proposes the adoption of the apparatus represented in Figs. 17 and 18, in which the blast is introduced through the vertical tube, *a*, formed of fire-bricks with an iron bar in the centre; the blast is emitted through the openings, *b*. The tube, *a*, together with

FIG. 17.

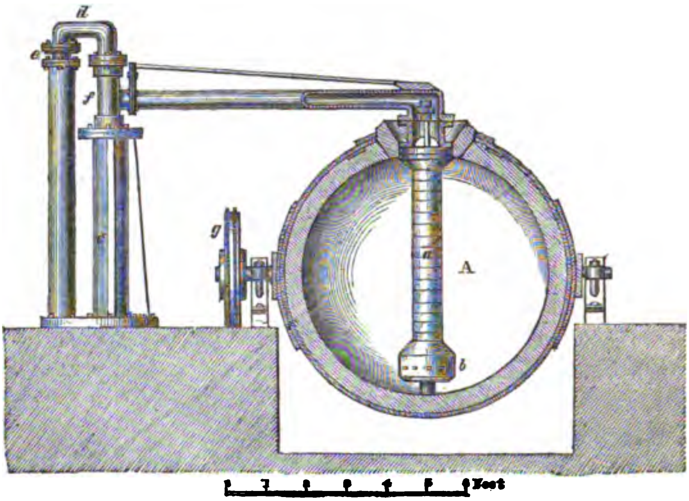
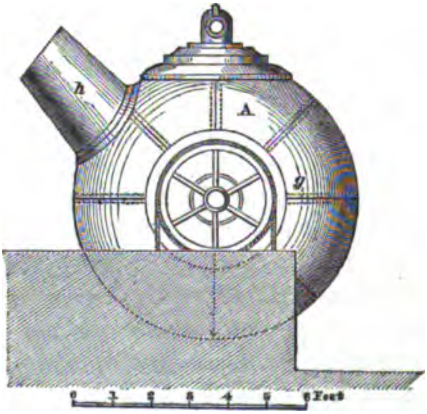


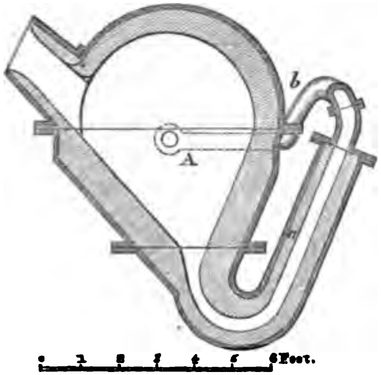
FIG. 18.



the horizontal blast tube, *d*, may be raised in the stuffing boxes, *e* and *f*, by hydraulic pressure in *c*; *g* is a drum for moving the converter, and *h* is the neck.

The apparatus represented in Fig. 19 is constructed by Wilson. The blast is here introduced by the tube, *a*, which, however, does not admit of a fine distribution.

FIG. 19.



Neither Fairbairn's nor Wilson's apparatus have yet come into practical use.

In Sheffield, about 2 or 2½ tons of ingots result from 3 tons of charged pig-iron; the loss of weight in the pig-iron amounts, therefore, to from 15 to 17 per cent, of which 5 or 7½ per cent are caused by the re-melting in the reverberatory furnace. With 3-ton converters, the lining has to be renewed after 250 tons have been blown, but the tuyeres wear out much quicker, and must be replaced after 10 tons have been made, that is, after every third or fourth operation.

The number of charges made daily does not amount to more than four for each converter, as, although the actual blowing only occupies about 20 minutes, a considerable time is required for the subordinate operations.

The ingots are chiefly worked into rails and boiler plates. In rolling rails, the ingots are raised to a bright red heat in a re-heating furnace, care being taken to keep the hearth filled with a smoky flame, in order to prevent the carbon from burning away. They are then hammered to a smooth face under a steam hammer, and at a second heat hammered down to the form of the first groove of the rolling mill; under the hammer the length of the ingots is extended from 4½ to 8 feet. Two heats more are then required for rolling the finished rail in about 12 grooves, causing a loss of 5 or 6 per cent of the ingots.

When the manufacture of boiler plates is designed, the steel is cast into plates 2 or 3 inches thick, and from 2 to 3 feet broad.

Spherical shot are cast a little larger than the size required, and afterwards reduced to the proper figure and dimensions by a steam hammer with hemispherical faces.

At present the largest Bessemer steel works in this country are those at Barrow-in-Furness. The converters are arranged in two groups, one of which has four 5-ton vessels in two pairs opposite to each other, so as to form the four corners of a square, in the centre of which are two sets of valves placed close together. The other set of converters is differently arranged, forming two groups of three vessels each. The three converters turn against the centre of a circular casting pit 30 feet in diameter, so that all can pour their contents into one ladle, if required. The hydraulic rams and racks for tipping the vessels are placed in a vertical position in order to gain space. These converters are constructed for charges of 7 tons; they are 12 feet 10 inches in diameter outside, and 11 feet clear diameter inside. The entire height is about 15 feet. In all cases the proportion of space occupied by the melted metal is very small as compared with the entire capacity of the converter, a large empty space being necessary to prevent the ejection of the fluid contents, when the boiling is at the highest point. The blowing engines have 36-inch horizontal steam cylinders, with 4-feet 6-inch blowing cylinders and 5-feet stroke. Two pairs of these engines are placed side by side. The pressure of blast for the converters is 21 or 22 lbs. per square inch, and the average duration of a charge, 25 minutes. The pig-iron is melted in Clayton's patent air furnace. Successful trials have been made to work these converters with liquid iron direct from the blast furnace. For this purpose, a ladle capable of holding 10 tons of molten pig-iron is mounted on an iron truck in a frame, which permits the ladle to be lifted off the truck by a crane, and tipped so as to pour out its contents. The ladle is filled at the blast furnace, and then taken to the converters upon the rails which connect the furnaces and steel works.

The ingots produced are re-heated in furnaces, some of which are constructed upon Siemens's patent principle, which in future will be adopted throughout.

The Atlas are at present the only Bessemer steel works in Scotland. The proprietors, Messrs. Rowan and Co., were among the first of Mr. Bessemer's licensees, and they started the Bessemer process for the manufacture of steel tyres and axles.

Mr. Rowan made interesting investigations of the flame issuing from the converters, an account of which was read at the meeting of the Chemical Section of the Glasgow Philosophical Society, March 29, 1869, by Mr. Rowan's brother, Mr. Thomas Rowan.* The following is his description, which will be found of great value:—

"The Bessemer process for the manufacture of steel, is now among the most important of our metallurgical operations. On account of its comparatively recent introduction among established industries, it affords an ample field for scientific investigation, and there is no feature of the process at once so interesting and important as that of the flame which issues from the converting vessel.

"The success of a 'blow' undoubtedly depends on the accuracy and completeness of many details, but of them all, the most important is to know and catch that moment in the existence of the flame, when the carbon has yielded its last trace to the oxygen of the air.

"If a charge is 'over blown"—that is, if it be subjected to the action of the air for too long a period, or if it be 'under blown'—that is, if the admission of air is stopped before the proper chemical action has been completed, the steel will be found to be defective in proportion to its unskilful treatment.

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* Chemical News, 1869, vol. xix., p. 170.

"The flame issuing from the converter is the index of these changes which the molten mass of metal is undergoing during the process; but the exact moment of decarburisation is often, from a variety of causes, difficult to determine.

"It is for these reasons that the examination of the flame forms the point of attraction of the process; and I have thought it might not be uninteresting to the members of this society to describe to them the general appearance which this flame presents to the eye, and some experiments which my brother has made with the spectroscope and with coloured glasses, for the purpose of more readily determining that critical period or 'change' in the flame which I have spoken of. The success of these latter experiments has enabled him to obtain the object for which they were commenced; and he has designed an instrument, which I shall describe hereafter, by which the change in the flame is more easily determined.

"1. **The General Appearances of the Flame to the Eye.**—When the vessel is first turned up, a shower of brilliant sparks is ejected, owing to the force of the blast reaching first a thin layer of metal as the vessel slowly swings round to the vertical position.

"*From* 0 *to* 3 *or* 4 *Minutes.*—When the full head of metal is over the blast, at first, for 3 or 4 minutes, there is scarcely any flame, only a current of very hot gases and very numerous sparks.

"*From* 3 *or* 4 *to* 5 *or* 6 *Minutes.*—Gradually a small pointed flame appears in the centre of the sparks, and this quickly increases in size, without gaining much brilliancy for 2 or 3 minutes.

"*From* 5 *or* 6 *to* 9 *or* 10 *Minutes.*—During the next period of 4 or 5 minutes the flame is very unsteady, both in size and in position, and its oscillations are accompanied by hollow sounds, as of reports or explosions in the interior of the converter.

"*From* 9 *or* 10 *to* 11 *or* 12 *Minutes.*—Streaks, or flashes of brighter flame now shoot up through this comparatively non-luminous flame, and within 1 or 2 minutes give place to a continuous stream of dense and brilliant fire, which rushes far up the chimney and illuminates the entire building, often casting the shadows of the cranes, &c., against the windows through which the sun is shining.

"*From* 11 *or* 12 *to* 15 *or* 16 *Minutes.*—The flame gradually becomes thinner and more transparent, without losing any of its brilliancy during the 6 or 7 minutes of the blow which generally remain, until it suddenly (preceded, however, by a few hollow and peculiar sounds from the interior of the vessel) loses its brilliancy and much of its size, and drops down, within about ½ a minute, to about the size it had reached at about 5 minutes of the blow; this flame, however, being more dense and more luminous than the flame at that earlier period.

"Any of the stages described may, from a variety of causes, be prolonged; or an insufficiency of blast, however caused, may lengthen the entire period of the blow for several minutes, but the above is a fair average blow with the best English hæmatite pig-iron. If inferior irons are used, the flame at the change is more or less enveloped in a dense white smoke, and the change is accompanied by violent pulsations or 'coughings,' of the entire flame, which, under these circumstances, has often a yellowish red colour to the eye; all this making the change often very difficult, if not impossible, to detect. Nervousness or biliousness, by variously affecting the sight of the observer, may also render him unable with certainty to determine the precise moment when he ought to 'turn down;' and there is a marked difference in the facility of observation noticeable between a blow taking place in daylight and one at night.

"2. **The Appearance of the Flame as Examined by means of the Spectroscope.**—It was important, first, to note if any of the lines belonging to the Bessemer flame were to be found in the flame given off from the coke fire used to heat up the converter. Several examinations were made; the result of these was that, besides the invariable yellow bright line, the red line, and the two bright green lines next the yellow, were occasionally to be seen. Owing, however, to the want of brilliancy of this flame, the spectrum which it gave was very faint, and, at times, almost invisible.

"On first turning up the vessel, and for about 4 minutes thereafter, the spectroscope showed only a continuous band of light, with the colours rather hazy, and so much blended with one another as to make it impossible to mark the junctions of the different fields.

"In from 4 to 6 minutes, flashes of the yellow line became visible (corresponding to the appearance of tongues of a bright flame, shooting up in the centre of the dull red one issuing from the mouth of the converter); and in 1 or 2 minutes after its first appearance, this line became quite steady, and did not disappear even at the end of the blow. Simultaneous with the steadying of the yellow line, the red, yellow, and green fields became clear and well-defined bands of bright colour.

"In ½ a minute to a minute later, a bright green line appeared near the yellow, following which, in scarcely ever more than ½ a minute, a red line appeared, equi-distant from the yellow (of course on the opposite side). These two generally became steady together (having first appeared in intermittent flashes) in about ½ a minute after both are visible. With the steadying of these two lines at once, a second green line (bright, and about the centre of the green field) became visible, wavering a little at first. About a ¼ of a minute served generally to steady it, although sometimes it was a minute and a half from the appearance of the first green line till the second green line with the red became steady.

"In 1 or 2 minutes, a third green line, nearer the blue field, came into view, and in about 1 minute was steady. When the red appeared with the first green line, the second and third green lines generally appeared together; but when the red appeared with the second green line, the third green was accompanied by a blue bright line near the green field. In about 10 minutes after turning up the converter, the flame attained its maximum size and intensity of light, when a second and third bright line became visible in the blue field. Very often these were only intermittent and very faint; but with 'hot metal,' and a bright flame, they were pretty steady and distinct, and were broader than those in the yellow, green, and red fields.

"Occasionally, for about 2 or 3 minutes before the close of the blow, a bright line was seen in the purple field, pretty far to the right of the spectrum; sometimes this only flashed brightly, but on a few occasions it was clearly seen, though faint.

"With a very bright flame, several dark lines were seen, but, for want of definiteness, it was impossible to say whether they were not due to the contrast afforded by the brilliancy of the bright ones beside which they appeared. A narrow dark line was seen on each side of the red line, and a broad dark band dividing the yellow from the green; then one between each green line, and two in the blue field, between the three blue lines. But these were only seen with an exceptionally bright flame, and, therefore, are not of much importance.

"All the bright lines visible remained steady for several minutes before the close of the blow, affording an excellent opportunity for their examination; but, at the last, all (with the exception of the yellow) faded in less than 30 seconds. The purple line disappeared first (whenever it happened to be visible), then the three blue lines, in the inverted order of their appearance, then the third green, after which the second, then the red, and last of all the first green, when the blast was shut off.

"The green and the red lines, from their distinctness, afforded the best point for a determination of the process; and these were so constant, that a sure indication could always be given by any of them, if it were made the index by which to determine the period of blowing.

"Very often, on adding the charge of spiegeleisen, a large and very brilliant flame rushed out of the converter for some minutes, and on examining it, the red, yellow, three green, and a very brilliant purple line were seen, but no blue.

" **3. Some Experiments with Coloured Glasses on the Flame.**—I shall now proceed to describe some experiments made with coloured glasses on the Bessemer flame. I may mention that what led to them was my brother being compelled to get very dark spectacles to protect his eyes, which were not very strong, from the intensity of the light of the flame. The first pair made completely overcame the brilliancy of the flame without imparting any colour to it; but, on ordering a second pair, they showed so much colour as to render them useless. On appealing to the workman who had made them, he found that no note had been kept of the kinds of glasses which had been used in the first pair; and, although several attempts were made to repeat them, the second pair sent was the best he could accomplish, and they had appeared colourless to sunlight. The thought then occurred, that, as the brilliancy of the flame varies considerably during its existence, a variation in the amount of transmitted light might be found to affect, in proportionate degree, the power of some coloured glasses to absorb other colours in combination with them, and that a combination of colours might be found to give, with a small quantity of transmitted light, a distinct colour, which could be quite absorbed when a larger quantity of light was passed through the same glasses.

" Another, and perhaps the most important, consideration which led to the following experiments, was that the flame itself has a varying chemical composition, as the silicon, manganese, carbon, and iron become successively attacked, and that the temperature of the flame at these various stages must necessarily be altered, giving rise, of course, to various colours, or shades of colour in the flame. If, therefore, a combination of coloured glasses could be found which would absorb the colour due to the flame at a particular temperature, it seemed clear that a change of temperature would become immediately visible, on account of an accession or diminution of colour to the flame as thus observed. It is probable, too, that the colour possessed by the flame at its different stages is due to the various elements which are at these periods being volatilised, but the spectroscope does not throw much light on this supposition.

"The first combination of coloured glasses which I have noted are a

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|---|---|
| Ruby and<br>Emerald. | It was found that these colours mutually destroyed each other. The Bessemer flame, when viewed through them, appeared white, and without brilliancy. |
| Ultramarine blue,<br>Dark yellow. | This combination gave the same effect as above. |

"With a combination consisting of—

| | |
|---|---|
| Ultramarine blue,<br>Dark yellow,<br>Ultramarine blue,<br>Emerald. | The flame appeared of an emerald colour, but was dark and without brilliancy. |

"In the next experiments, the dark yellow and one blue were replaced by a light yellow and neutral tint, thus:—

| | |
|---|---|
| Ultramarine blue,<br>Light yellow,<br>Neutral tint,<br>Emerald. | The appearance of the flame in this case was similar in colour to that afforded by the above combination, but appeared of considerable brightness. |

"In the next experiments, the light yellow and neutral tint were replaced by a dark yellow and red, respectively, thus:—

| | |
|---|---|
| Ultramarine blue,<br>Dark yellow,<br>Ruby,<br>Emerald. | The flame at first was dimly seen, and without colour; when it reached its maximum brilliancy, it still appeared white through this combination. |

"With these five combinations, the appearance of the sun, as seen through each of them, was similar in character to that of the flame, but more powerful in degree.

"In the subsequent experiments, the combination was as follows:—

| | |
|---|---|
| Ultramarine blue,<br>Dark yellow,<br>Neutral tint<br>Ultramarine blue. | The flame appeared at first of a ruby-red colour, increasing in size and intensity as the blow progressed, the edges of the flame acquiring a lighter shade of red, but the colour was too strong to admit of the changes being easily determined. Sunlight, through this combination, was slightly yellow. |

"In the succeeding experiments, one of the blue glasses was replaced by a light yellow, giving a combination of—

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| | |
|---|---|
| Ultramarine blue,<br>Dark yellow,<br>Neutral tint,<br>Light yellow. | The flame appeared at first of a yellowish red colour; as the blow progressed this colour became whiter, with flashes of redder flame occasionally through it. At the flame's maximum brilliancy, the edges assumed a light red colour (nearly white), while at the root and centre of the flame the colour was of a darker yellowish red. When the flame dropped (at the end of the blow), it returned to a yellowish red colour, somewhat similar in appearance to the effect produced at the beginning of the blow. Sunlight appeared slightly yellow. |

"It will be observed that this combination gave nearly the desired effect—viz., a variation of depth of colour due to the differences of temperature or brilliancy of the flame at its different stages of progression. The yellowish tint, however, always present, showed a defect in this combination, to overcome which further trials were made. Among other devices, the light yellow was omitted, and the flame was observed with—

| | |
|---|---|
| Ultramarine blue,<br>Dark yellow,<br>Neutral tint. | The flame appeared still red, and with the yellowish tint, though in such small degree as to show that the desired result was not far off. Sunlight appeared dim, and slightly yellow. |

"In the concluding experiments, the neutral tint was replaced by a blue glass, with the object of ascertaining whether the yellow colour could be corrected, by the omission of the red or the blue component of the neutral tint, thus:—

| | |
|---|---|
| Ultramarine blue,<br>Dark yellow,<br>Ultramarine blue, | This combination was perfectly successful, the lingering trace of yellow being removed. |

"I shall now describe more fully the appearance of the flame through it.

"For the first 4 or 5 minutes all is dark; the chimney is invisible; nothing but the mouth of the converter can be made out, which appears slightly red, the sparks coming from it being scarcely visible. As the blow progresses, the flame, still red in colour, increases in size and luminosity, while the outline of the vessel becomes visible. In about

12 to 15 minutes the flame begins to lose its colour, becoming violently agitated, flashes of a lighter and brighter flame shooting up occasionally.

"In about 15 minutes a purple tint becomes visible round the mouth of the vessel, the flame gradually acquiring a white colour towards the edges.

"When the flame has reached its maximum brilliancy it appears bright and nearly white, with the edges purple. The red colour thereafter begins to re-appear at the mouth of the vessel and centre of white flame, gradually extending until the whole flame appears of a light red colour.

"And with the peculiar hollow sound heard in the vessel always preceding the drop, the centre of the flame begins to acquire a deeper colour; this quickly extends and deepens. Within a minute or so of the drop, the whole flame becomes crimson, and losing its brilliancy, and within ½ a minute, it suddenly goes back to very nearly the red colour it had at starting.

"This combination of glasses is now in daily use in the Atlas Works, its indications being so marked and unmistakable as to render its use safe in the most inexperienced hands. This little instrument or 'Chromopurometer,' as it is proposed to call it, is arranged as follows:—

"One of the blue glasses and the dark yellow one are fixed in a rectangular frame, carrying at its foot a hinge to which the thin frame holding the other blue glass is attached, and at its top a spring catch to hold this smaller frame when in its shut position, and also a pin and set screw for attaching the whole instrument to the hat of the observer so as to place it before his eyes.

"The object of having the glasses thus divided is to give facility for the observation of the flame through the combination of three, while, during the pouring two being sufficient, the third one is allowed to hang down, when it serves to protect the lips from the great heat of the ladle and liquid steel.

"I think it is probable that, by carefully noting by means of coloured glasses such as that described, the amount of light (as determined by the shade of *colour* visible) emitted by flames of known temperature, a scale might be formed which would enable us approximately to measure the temperature not only of the flame of the Bessemer Converter, but also that of many flames which have hitherto been considered beyond the reach of our ordinary methods of measurement."

**The Dowlais Iron Works in South Wales** have six converters of 5 tons each. The two blowing engines have 36-inch steam cylinders, 54-inch blowing cylinders, and 5-feet stroke. The same kind of pig and spiegeleisen are used as in Sheffield, and the quality of steel is equally good. Instead of ganister, the Dinas sand with a mixture of one-tenth of its bulk of fire-clay, is used for lining the converters, and the material continues good for 300 charges. The ingots intended for rails are made of sufficient weight for two rails instead of one, and the ingot is cut in two under the hammer. This saves one crop-end, and will secure, on the whole, better work.

**The Manchester Steel Works** employ two pairs of 5-ton converters. Contrary to the usual practice, the pig-iron is melted in cupola instead of in reverberatory furnaces. The cupola is one on Messrs. Woodward's patent principle, being 3 feet in internal diameter, and 20 feet in height; it is found more advantageous than reverberatory furnaces, though of course a careful selection of the coke is necessary. The cupola in regular working, melts a charge for one vessel in two hours, at a consumption of about 1¼ cwts. of coke per ton of pig-iron; from 6 to 8 cwts. of coal are required for melting 1 ton of pig in reverberatory furnaces. When coke of sufficient purity is used, the resulting steel is not found inferior to that produced from iron melted in reverberatory furnaces.

The ingots, blooms, &c., are re-heated in Siemens's gas furnace.

**The Neuberg Iron and Steel Works in Austria.**—These works, so far as the quality of the products are concerned, are generally considered to be the most successful Bessemer steel works in the world. Their apparatus consists of two 3-ton converters, of somewhat smaller diameter and of comparatively greater height than the 3-ton vessels usually made in England; the throats especially are very narrow, and may, in all probability, cause an undue amount of back pressure upon the blast. The pig-iron is used direct from the blast furnace; it is collected in a ladle, mounted on a truck, and run upon rails to the converter.

During the first stage of the process, before the white flame makes its appearance at the mouth of the converter, a considerable quantity of charcoal powder is blown at regular intervals through the liquid iron, along with the blast. This is done for the purpose of heating the charge by the combustion of the charcoal within the vessel, and is said to be particularly effective when white iron, or iron containing a small percentage of carbon is worked in the converter. With this exception the process is carried on in the usual manner.

The use of spiegeleisen is entirely dispensed with, and in its place, a proper quantity of liquid iron from the same blast furnace that has supplied the whole charge, is added.

Professor Liellegg, in conducting the Bessemer process in the steel works at Gratz, has employed the spectroscope with success.

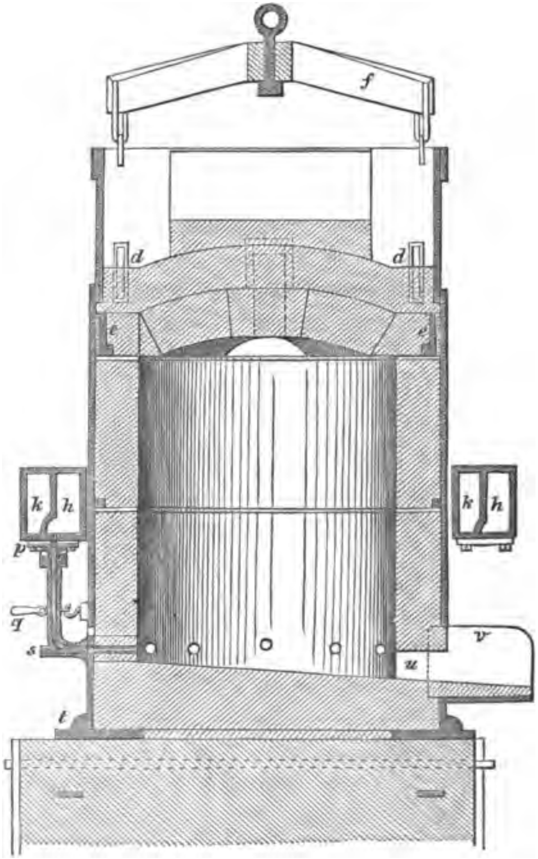
### The Swedish Method of conducting the Bessemer Process.

The apparatus used in this method has been mentioned before (page 97), when the English and Swedish methods were being compared.

In the newer plants, the sole of the blast furnaces is about 12 feet above that of the fixed converter, and the moulds are placed on a sole 6 feet lower again. The furnaces for reheating the ingots are best, because most economically, heated with the waste gases of the blast furnaces. These waste gases may also be employed for the preparatory heating of the converter, the ladles, and the necessary boilers.

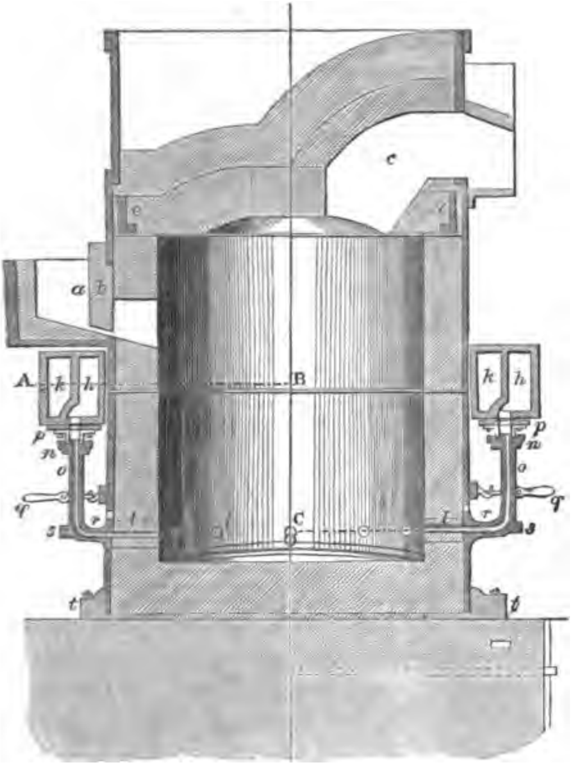
The converters are mostly constructed like that used in Edsken, in Sweden, which is represented in Figs. 20, 21, and 22. *a* is a sort of funnel, through which the converter is charged with the liquid pig-iron; *b*, a fire-brick for closing the charging opening; and *c*, the neck whence the gases are evolved. The iron ring, *e*, supporting the furnace roof, is connected with the ears, *d*, which may be again connected with the cast-iron beam, *f*, for removing the furnace roof; *g* is the blast main containing two compartments, *k* and *h*; the latter conducts the blast into the tuyeres, *i*, which introduce the blast into the converter in an eccentric direction, and the compartment, *k*, was formerly used to provide an upper row of tuyeres with blast; *l* and *m* are valves; *n* is a screw-box by means of which the blast pipe, *o*, may be moved up and down. This pipe is also movable at the polished ring, *p*.

FIG. 20.



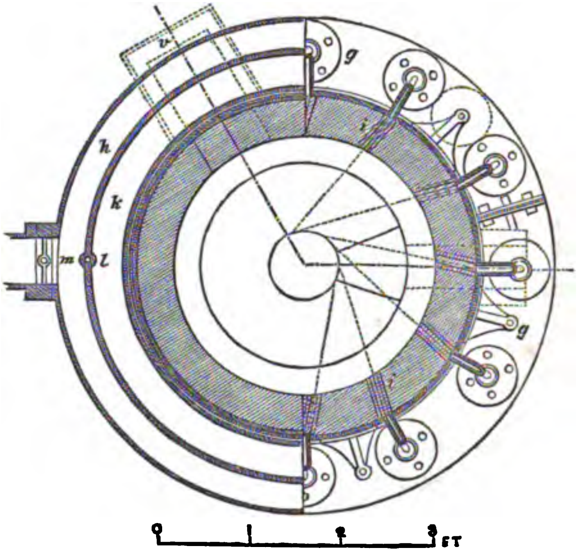
The handle, *q*, provided with an eccentric motion, serves to press the blast pipe hard against *r*; *s* is an opening for cleaning the tuyeres, and may be closed; *t* is the cast-iron bottom plate of the converter; it is screwed to the foundation; *u* is the tapping hole, closed with a clay plug; *v* is a gutter for running the steel into the ladle. The twelve tuyeres of clay are $\frac{3}{4}$ of an inch in diameter, and are placed 2 inches above the bottom in a tangential and not a vertical direction, as, in the latter position, the metal attains a rotatory movement, which impairs the uniformity of the process. The quantity of blast required and its pressure have been mentioned on page 102.

FIG. 21.



More recent improvements have been made in these converters by Stefanson, of Siljansforshütte, by placing the wind box, *h*, deeper and close to the converter, so that the blast is introduced into the converter direct from the wind-box, through nineteen tuyeres of ¾ of an inch in diameter. The tuyeres communicate with the closed openings of the wind-box, by which means they may easily be replaced; they also burn out less, and the leakage of the fluid metal is prevented, as the pressure of the metal column is balanced by that of the blast, on all places where a leakage is likely to occur. The converter is 4 feet wide, and from 38 to 50 inches high, the wind-box is 7½ inches high and 6 inches wide, and the opening for charging, 3 inches square, lies 2 feet above the sole of the tapping hole, which is 4 inches square. The neck of the converter measures 6 by 9 inches, or 54 square inches. The height of the furnace varies with the nature of the pig-iron. The English fire-bricks prove cheaper and more refractory than the Swedish bricks of Höganä.

FIG. 22.



The blast engines employed for treating charges of from 36 to 40 cwts. of pig-iron, are horizontal cylinders 2·5 feet in diameter and 3 feet stroke of quick motion, making 120 double strokes per minute; they work at a pressure of 5½ or 5¾ lbs. per square inch. The motive power required, corresponds to about 107 horse power, or, when the friction is taken into consideration, to 150 horse power. The blast is introduced into the converters through nineteen tuyeres, each of ¾ of an inch in diameter.

The blast regulators must be large enough, and must comprise at least ten times as much space as that which the piston passes through in a second.

The ladles are made of iron plates and are coated inside with clay; they are of larger dimensions for soft than for hard steel, as the former boils up more violently. To prevent the steel cooling too quickly, the ladle is surrounded with an iron mantle, and the space between the mantle and ladle is filled up with bad conductors of heat. The larger kinds of ladles are about 3½ feet high, and 3 feet and 3½ feet in diameter at the bottom and top respectively. The ladles are also constructed like those described on page 122.

The moulds are made of cast-iron, free from sulphur, and are cast in two parts; this construction is a disadvantage, as seams will be found in the ingots along the lines of junction of the moulds.

**The Conduct of the Process.**—The pig-iron (1½ or 2 tons) is tapped into a well warmed ladle, and after being weighed it is charged into the converter through the funnel, *a* (Fig. 21); as much blast is at the same time introduced as is required to blow out the coal which has been employed for warming the converter, and to offer sufficient resistance to the entering mass of fluid iron. The outside of the roof of the converter must be warm to the hand. While charging the iron, the quantity of blast is so much increased that, after some minutes, ebullition takes place. In order to effect the charging so quickly that no ebullition occurs during the operation (which would cause much iron to be thrown out of the converter by the blast), the opening in the ladle for emitting the iron ought to be 2 inches wide, and that in the funnel 3 inches square. The charging being finished, the opening of the funnel is closed with a plug of loam, and its top covered with a weighted cast-iron plate.

The formation of the slag, by the oxidation of silicon, manganese, and iron, now commences, and the graphitic carbon is converted into combined carbon. The flame, which is short and of a dull yellow colour, with comparatively few sparks, makes a hissing noise in the converter; the metal is put in violent motion, and if the iron is thickly liquid, it will partially close the tuyeres, causing the manometer to rise; the pressure of the blast must then be increased. The ebullition commences either immediately after the pig-iron is charged, or in the course of not more than 17 minutes after, according to the nature of the pig-iron, the largeness of the charge, and the quantity of ferriferous slag of the previous charge, remaining in the converter; when the ebullition commences, and also when grey pig-iron is being treated, the tuyeres will be open and the scale of the manometer be lowered. Part of the carbon is now oxidised, forming carbonic oxide, and the commencement of this period is indicated by the following appearances:—A great number of woolly looking sparks are emitted from the converter, the flame contains intermixed violet stripes, and the noise in the converter increases if the process is carried on more vigorously and at a higher temperature; the flame then becomes long and of a blue colour, with a brilliant white edging, and emits a greater quantity of brown smoke if the ebullition is very strong and the pig-iron very hard. A satisfactory ebullition is indicated by a loud buzzing noise and but few wool-like sparks.

The blast must be so regulated, by means of a valve in the blast main, that a brisk ebullition, without brown smoke, takes place, and that as little as possible of the iron is thrown out of the converter. When too little blast is introduced, the flame will oscillate and be dull and free from sparks, and the ebullition will decrease. The throwing out of metal may also be counteracted by heightening the converter, which, however, is limited by the degree of liquidity and the temperature of the metal, and by making the neck of the dimensions stated on page 140.

Grey pig-iron boils uniformly without any noise, and permits a stronger pressure of the blast, whilst harder pig boils intermittently, emits a great deal of brown smoke, and throws out fragments of burning iron, defects which cannot be easily remedied by lowering the blast, and the loss is increased as a longer time is required for boiling.

When the emission of burnt iron becomes less violent, the blast is gradually increased until the boiling ceases, less smoke issues, the wool-like sparks disappear, and the appearance of the fragments of burnt iron and the noise in the converter indicate a hot and thoroughly liquid product. About as much blast is applied as will limit the ebullition of 30 cwts. of grey pig-iron to 6 minutes at the most. But the metal is not yet converted into steel, and still contains 2·5 or 3 per cent of carbon, which is removed, as far as necessary, in the last period by applying more or less blast for 1 or 2 minutes longer, according to whether the production of hard or soft steel is intended. This period is characterised by a pure brilliant flame and reddish fragments of burnt iron, which, on touching the wall of the building, appear black, and grow gradually lighter, till, at last, they attain the appearance of a steady, strong train of light. With the progress of the fining the particles of iron become lighter, and, at a very high temperature of the converter, sometimes disappear altogether, the flame becomes shorter, and instead of the roaring noise in the converter, a humming or buzzing takes place.

Much experience is required to produce steel of a certain degree of hardness from calculations founded on a number of indications, such as the size and nature of the flame, the time occupied for boiling at a certain state of the manometer, the colour and brightness of the particles of iron thrown out, &c. However, the managers of the process are able to obtain a product regularly for some weeks which does not vary by ¼ of a per cent of carbon. Two different states of the process are distinguished, one of which is termed "warm" and the other "cold," and these states are essentially influenced by the quality and quantity of the pig-iron charged, by the state and dimensions of the converter, and by the quantity of blast employed.

*A warm process* requires a good grey pig-iron, charges of the size fixed by experience, a sufficient number of tuyeres, and a low well-constructed furnace. It is indicated by a roaring noise in the converter during the stages of the boiling and fining, whilst little fragments of burnt iron are thrown out; the product undulates strongly in the ladle, and on being cast in the moulds, the slag is a light brownish-yellow. A *cold process* is characterised by the opposite indications.

The tapping-hole is closed with a fire-brick supported by an iron plug, and is opened as soon as it is apparent, by the above-mentioned indications, that the steel has attained the desired degree of hardness. The blast is then almost entirely put off, whilst the steel is collected in a ladle, the bottom of which has previously been heated to redness.

If the tapping off is not effected quickly, the metal is apt to become further decarbonised, and even converted into wrought-iron. The ladle is then moved above the iron moulds, which are previously heated so as to be hand-warm, and the moulds are filled with steel up to within 6 inches of the top. If, owing to small size of the moulds, the very hot process, and the strong stream of steel, the surface of the steel in the moulds sinks, the tapping-hole of the ladle is alternately opened and closed, until no further sinking is observable. A plug of cast-iron is now placed upon the steel surface, and the space above filled up with sand. Heavy and flat ingots are cast with a stream from below, thus preventing their upper surface becoming hollow and uneven.

If, during the operation of casting, some steel is collected by means of a shovel placed below the ladle, hard steel will form dark spots owing to a rapid crystallisation, and, on cooling, will present an even surface. Soft steel does not crystallise, is rugged when solidified, and in the liquid state shows a white colour, emitting a number of fine, white, round sparks.

When the converter has been emptied, its tapping-hole, neck, and bottom, together with the tuyeres and other parts, are cleaned and repaired, while the movable roof is removed, and some of the blast employed for cooling the furnace if necessary. The converter is then warmed and ready for a new charge or blow.

About 78 per cent (sometimes even 80 per cent) of steel are produced from the pig-iron, 70 per cent of which are pure ingots, and 8 per cent are waste steel. There also result 10 per cent of metal which is blown out of the converter; this is collected and added to the ore mixture for the iron blast furnaces. On re-heating and rolling, a loss of 4 per cent takes place.

With regard to hardness, the Bessemer products are usually classified according to the appearance of the fracture of the ingot and of a drawn-out bar, the temperature at which steel can be treated without crumbling, and the lowest degree of heat at which the steel may be hardened.

But such an examination of steel requires great experience. Eggertz's colorimetric method for quickly determining the combined carbon in steel, may, therefore, be considered as an essential progress in the classification of this metal. The Swedish works, as well as some of the Bessemer steel works in England, have adopted Professor Eggertz's method.

This method of determining combined carbon in iron or steel, depends on the coloration produced by carbon in solution of pernitrate of iron, which, under ordinary circumstances, is colourless, or, at most, of a slightly greenish tint. The standard series of colours is made by dissolving quantities weighing 1 decigramme of steel of known composition in pure nitric acid of 1·2 specific gravity at 80° C., and diluting with water to a standard volume. The solutions, which give different shades of brown, are preserved in glass tubes.

One decigramme of the steel to be examined is dissolved in pure nitric acid, under the conditions observed in making the standard series. The solution is decanted from the residue, poured into a burette of the same diameter as the tubes containing the standard solutions, and diluted with water until it matches one of the tints. The amount of carbon is then found by calculation from the relative volumes of the solutions. Steel, with a medium amount of carbon (0·8 per cent) gives a yellowish green solution, a very hard steel with 1·5 per cent, brownish red, and the softest steel with 0·4 per cent, only a slight greenish tinge.

The following determinations of carbon in various kinds of iron and steel made in Sweden are by Eggertz:—

| | | | |
|---|---|---|---|
| Softest Swedish Bessemer iron contains | 0·08 | per cent of carbon. | |
| Soft steel | 0·75 | ,, | ,, |
| Best quality of cast-steel | 1·40—1·50 | ,, | ,, |
| Natural forge steel | 0·99—2·44 | ,, | ,, |
| Cement steel | 0·50—1·90 | ,, | ,, |
| Cast-steel | 0·86—1·94 | ,, | ,, |
| Hardest welding cast-steel | 1·80 | ,, | ,, |
| Malleable cast-iron | 0·88—1·52 | ,, | ,, |
| Draw-plate steel | 3·30 | ,, | ,, |

The Fagersta works in Sweden* produce their own pig-iron from a mixture of ores, principally "magnetic," in charcoal furnaces with hot blast. The iron mostly produced for the Bessemer process is grey, and the ore mixture employed for that purpose has the following composition:—

| | |
|---|---|
| Carbonic acid | 8·00 |
| Silica | 17·35 |
| Alumina | 0·95 |
| Lime | 6·50 |
| Manganese | 3·35 |
| Sesquioxide of iron | 32·15 |
| Protoxide of iron | 27·40 |
| Phosphoric acid | 0·03 |

The grey pig-iron produced has the composition shown in column 1:—

| | I. | II. |
|---|---|---|
| Combined carbon | 1·012 | 2·138 |
| Graphitic carbon | 3·527 | 2·773 |
| Silicon | 0·854 | 0·641 |
| Manganese | 1·919 | 2·926 |
| Phosphorus | 0·031 | 0·026 |
| Sulphur | 0·010 | 0·015 |

No. 2 is called two-thirds mottled, and is also produced for the Bessemer process, in which it is used, together with the grey iron, in the proportion of about 1 to 2.

The composition of the slag produced in the converter with grey iron, after a complete charge in making soft steel, is shown in analysis 1; analysis 2 shows the composition of the corresponding blast furnace slag:—

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* F. Köhn, Manufacture of Iron and Steel, p. 211.

| | I. | II. |
|---|---|---|
| Silica | 44·30 | 53·30 |
| Alumina | 10·80 | 3·00 |
| Lime | 0·65 | 21·10 |
| Magnesia | 0·15 | 13·95 |
| Protoxide of manganese | 24·55 | 7·85 |
| „ iron | 19·45 | 0·90 |

The Swedish classification of Bessemer steel, by numbers based upon the percentage of carbon, is as follows:—

No. 1·0 contains 2·00 per cent.
„ 1·5 „ 1·75 „
„ 2·0 „ 1·50 „

and so on up to No. 4·5 with only 0·25 per cent, below which point the scale is not extended, as this metal is already classified under wrought-iron. Sorts of steel containing proportions of carbon which stand between the given numbers, are called by the number to which they approach nearest.

The Bessemer process is interrupted at the moment that the desired quality of steel is obtained in the converter, and this precise moment is recognised by no other indication than the colour and appearance of the flame. Occasionally, the addition of a further quantity of pig-iron is resorted to, but this iron is instead of spiegeleisen, and is exactly the same as that employed in the charge.

At the last Paris Exhibition, the Fagersta Works had a series of bars of Bessemer tool steel, which had undergone the process of hardening and re-heating from one to fifty times. There was some visible difference in the grain of the original steel and that which had been hardened and heated many times, but the properties of steel had not been destroyed by the repeated process.

At the Königin Marienhütte, near Zwickau in Saxony, the quality of the steel is tested by the colour of the slags.* The iron used at these works is the product of the adjoining blast furnaces, mixed with a certain percentage of iron from the Georgs Marienhütte, near Osnabrück in Hanover. Both these makes have the peculiarity of evolving an extraordinary amount of white smoke towards the end of the charge, which makes the changes of the flame almost invisible, or, at least, very difficult to observe; the workmen have, therefore, been driven by necessity to adopt another mode of testing the progress of the charge than the observation of the flame. They insert a testing rod of iron into the converter, and upon this rod allow a small quantity of the converter slags to collect. During the early stages of the process, the slag, when solidified, shows a rough and dull surface covered with little metallic pearls; but, at the later stages, the surface of the slag is perfectly smooth and uniform, taking a yellowish brown colour when the harder kinds of steel are arrived at, and gradually passing through darker and darker shades into a bluish black. They use no spiegeleisen at these works, consequently, the testing rod has become their sole guide; and it is so reliable, that out of 100 charges no more than two or three prove defective. The test is finished in less than half a minute, as the slag solidifies almost instantaneously.

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* F. Köhn, Iron and Steel Manufacture, p. 111.

To complete our description of the Bessemer process, we subjoin a description by Mr. Bessemer himself, contained in a paper read on September 8th, 1865 (Ure's Dictionary, vol. iii., p. 767), before the Institution of Civil Engineers, which shows the gradual progress and present success of the process, and is also of historical value:—

"The facility which the blast furnace affords, of at once separating from the ores of iron the greater part of the extraneous matters which they contain, has rendered its employment almost universal, as a preliminary process in the production of malleable iron.

"The crude metal thus obtained, although separated from a large proportion of its impurities, is nevertheless found to be intimately combined with carbon and silicon, and generally with sulphur, phosphorus, manganese, and some other substances, in comparatively minute quantities; the decarbonisation of the iron, and the separation of these substances, as far as practicable, claims the first care of the manufacturer. For this purpose the crude metal is either formed into pigs, which are afterwards re-melted in the refinery furnace, or it is run, while still in a fluid state, from the blast furnace direct into the refinery fires, where it is subjected to the action of blasts of air, directed downwards upon its surface at a particular angle. The crude metal thus acted upon by the oxygen of the air, is in about three hours sufficiently decarbonised and refined to render it suitable for the puddling process; it is therefore run out of the finery and formed into a large flat plate, which is of an extremely hard and brittle character, and presents physically no approach whatever to the malleable state. The hard and brittle mass, thus formed, is easily broken by the hammer, into pieces of a size suitable for the puddling furnace, to which it is conveyed in order to be more completely decarbonised and rendered malleable.

"Most metals, on the verge of fusion, lose their power of cohesion, and are readily crumbled down into a coarse powder. This property is common to pig and to refined iron, and advantage is taken of it in the puddling process. The workman watches the temperature and appearance of the metal, and seizing the proper moment, divides the masses of refined iron into small fragments, which he spreads about the furnace, and finally breaks it down into a kind of coarse sand. The metal, in this divided state, exposes a large extent of surface to the refining action of the fluid cinder, as well as to the volume of air constantly passing through the furnace. By increasing the heat, the granulated mass swells up and emits numerous jets of blue flame. At this point the puddler diligently stirs and works the metal, until the flame appears of white colour, and the metal becomes clotted and tenacious, or, as the workmen term it, comes to nature; after which the iron is gathered into balls, and is then removed as quickly as possible to the squeezer, where much of the liquid scoria and other mechanically mixed impurities, are driven out, leaving a mass, or billet of iron, composed of thousands of separate fragments of metal, the entire surface of every one of which is more or less coated with dry oxide, or fluid silicate of oxide of iron. The great pressure exerted by the squeezer suffices to so far remove the fluid coating of contiguous particles as to bring their surfaces into actual contact, and consequently to effect an union at such parts. The whole of the matter thus displaced cannot, however, find its way between the interstices of the mass to the outside, but portions become locked in the hollows and cavities of the porous mass, and these produce points of separation, and consequently of weakness, from the want of contact of metal to metal. So marked is this effect, that in rolling the billet of squeezed iron into a puddle bar, large gaping cracks are formed at the angles of the bar, and a general want of cohesion is evinced by the ease with which it may be broken up, and by its fracture not taking place on the line of force, but following some tortuous path through the metal where the points of coherence are least. It must be observed that this source of inequality and weakness in iron is inherent to the puddling process, and that no amount of after rolling, or working, can entirely get rid of the extraneous matters, such as cinders, dry oxide of iron, and sand. These substances may, by working, be more generally diffused throughout the mass, and thus become less perceptible, but they will, nevertheless, for ever remain there, lessening the cohesion of the iron, and causing cracks and flaws more or less objectionable.

"In the puddling process, the granules of metal gradually pass from the state of brittle finery iron to steel, and passing that point through every gradation of hard, medium, and soft steel, eventually arrive at the softest stage of decarbonised iron. The time occupied in these charges varies with the size of the granules, their temperature, and the extent to which each is exposed to the action of the air passing through the furnace. The puddler, therefore, exercises his skill in bringing every particle, as far as possible, in turn to the surface, and by laborious and continued stirring and turning over of the heavy mass, he endeavours to bring the whole into the same condition; but, despite his skill and laborious efforts, he can only get the general bulk of the metal into the desired condition. There will always be pieces which elude his vigilance, which remain too long at the bottom, or lie snugly in some angle of the hearth during the greater part of the process, and then come forth to contaminate the rest.

"It is supposed, by many persons connected with the manufacture of iron, that it is to the puddling process that the fibrous texture of bar iron is due, and that the iron is, while in a pasty state, worked and kneaded in such a manner as to prevent the formation of crystals. Nothing, however, can be more erroneous than such an opinion. The puddling process has nothing whatever to do with the fibrous character of bar iron. In proof of this, an experiment was made on a squeezed and on an unsqueezed puddled ball, chosen as fair examples of good puddled iron, and obligingly supplied to the author by Mr. Clay, of the Mersey Iron and Steel Works. One of these puddled balls, which had been well squeezed and formed into a billet, was partly cut through in a lathe; it was then broken, and when the fracture was examined, the entire surface was found to be composed of large brilliant crystals, without the remotest approach to fibre. The unsqueezed puddled ball was next broken: the points of contact of the spongy mass were necessarily small, yet, wherever a fracture could be obtained through the solid mass, instead of between the separate granules, the fractured part exhibited a brilliant crystalline structure, the crystals being exceedingly large in proportion to the mass divided. In some cases, two small contiguous pieces separating from each other, the flat plane of one large crystal forming the entire of the fractured surface. It must be understood that this was the general condition of the mass, which was, however, interspersed with the hard rounded lumps, always found in puddle balls, and which, in this instance, exhibited a fracture dull and greyish in colour, not flattening under the hammer like malleable iron, but cracking like annealed finery iron, or steel of an inferior quality. The high reputation enjoyed by the Mersey Steel Company is a sufficient guarantee that the defects, here pointed out, are inherent to the puddling process, and are not the result of any inferior workmanship in the specimens. In the rolling process, the general mass becomes elongated, and the hard lumps of ill-refined metal become elongated also; but as they possess very little malleability and cohesion, large cracks and flaws are produced, and the bar, after the first rolling, shows most incontestably the extent to which these hard pieces, and the scoria together, operate to prevent the cohesion and uniform extension of the bar. Hence the rolled metal, in that state, cannot be used, and requires to be cut into short pieces, piled and rolled out, before a merchant bar can be obtained of sufficient soundness for general purposes.

"Now, if these imperfections are the natural and inevitable consequences of the conditions under which malleable iron is at present produced, it follows that defects of a similar character must also, of necessity, exist more or less in steel produced by the puddling process. The granular condition of the metal and its exposure to heat and oxygen cannot fail, in both cases, to oxidise the entire surfaces of the numerous granules to be united into one mass. The admixture of scoria and other matters from the furnace is equally certain to result, and, at the same time, the difficulty of bringing each particle of the metal to the same degree of decarbonisation and refinement exists as in the making of iron, with the additional inconvenience, arising from some portions of the metal becoming entirely decarbonised and converted into soft malleable iron.

"It is thus evident that iron, in its malleable state, presents an unfavourable contrast to the other malleable metals; for they are known not to possess the inequalities found in iron; they are free from sand and scoria, and have no hard and soft parts; nor do they require any welding of contiguous surfaces, but are perfectly homogeneous and free from all mechanical admixture with foreign substances. To what, then, do the metals, gold, silver, copper, zinc, tin, and lead, owe this valuable exemption from the defects universally found in puddled iron? The answer is found in the simple fact that all these metal are purified and refined in a fluid state, and while still fluid, they are formed into ingots. By this process any impurities float on the surface of the fluid metal, and are effectually separated from it; while a pure metallic mass is formed, connected at all points, and capable of producing plates of a degree of soundness and evenness of texture not hitherto met with in iron.

"The ingot, of whatever metal it may be formed, crystallises on cooling, in a manner peculiar to itself, all cast ingots being necessarily of a crystalline structure. Yet this condition of the metal, so much, yet so needlessly, dreaded by the iron manufacturer, in no way lessens the toughness of the sheets of metal produced from such ingots. Of this fact *zinc* presents, perhaps, the most striking illustration. In the cast ingot the crystals are of great size, and the lines of cleavage are so well defined, that on bending the ingot to a slight angle, cracks make their appearance and the mass separates, presenting a brilliant foliated surface. But if the ingot be rolled at a suitable temperature, an extreme degree of toughness is produced, and the whole structure of the metal is changed.

"If, then, the refinement of the malleable metals, while in a fluid state, and their formation into cast ingots, render all such metals more sound and homogeneous than iron, while the process does not lessen their extreme ductility, why should iron for ever remain an exception to the general rule? Why should it be attempted to stick dirty little granules of that metal together, and then to squeeze the impure mass until it is so small as to be useless, until it is again fagotted up and imperfectly united, and thus for ever to multiply the defects which its first treatment entails? It may be truly answered that hitherto the excessive high temperature required to fuse and to maintain pure iron in a fluid state, has interposed an insuperable barrier. The highest heat of the furnaces will only suffice to show that fluidity is a possible condition of that metal, but no use can be made of that property, on a commercial scale, with any fuel-consuming furnace at present known.

"It need not, therefore, be a matter of surprise that when it was first proposed by the author to convert crude pig-iron into malleable iron while in a fluid state, and to retain the fluidity of the metal for a sufficient time to admit of its being cast into moulds, without the employment of any fuel in the process, that his proposition was almost generally looked upon as a chimera, or as the mere day-dream of an enthusiast, which the quiet every-day practical man felt bound to disbelieve, although the laws on which the whole theory of the invention was based were well known, and hence the process was recognised from the very first by many of the scientific men of the day. The theory which was advanced in the original paper read at the British Association at Cheltenham, in August, 1856, and the experiment subsequently shown in London, sufficed to demonstrate three most important and incontrovertible facts:—1. That crude pig-iron could be wholly decarbonised while still retaining its fluid state. 2. That by the injection of atmospheric air into the fluid metal, the combustion thereby produced would, in the absence of fuel, raise the temperature of the metal to a degree never before attained in metallurgical operations. 3. That the iron so decarbonised without the employment of fuel would retain its fluidity long enough to enable it to be cast into ingots capable of extension under the hammer or the rolls. Nothing that has since been discovered has altered, or even modified, these facts. The same apparatus as that shown in London nearly three years ago will, with the proper quality of pig-iron, and the practical knowledge since acquired, produce both malleable iron and steel equal to any of the samples now exhibited. It is singular to observe how prone the practical man is to deny to the inventor of a new process that very practical knowledge which he himself so much values. If the inventor cannot show in the first week of his apprenticeship the skill which it is well known can only be acquired by years of practice, it suffices to condemn the new system, which, in its mere infancy, is expected to be as perfect in all its details as that which the manufacturers have grown grey in the daily practice of. The same deep conviction of the truth on which the new process is based, and which led the author to bring it before the British Association, has since determined him (in spite of the opinions loudly expressed against the process) to pursue one undeviating course until the present time, and to remain silent for years under the scepticism of those who predicted its failure, rather than again to bring forward the invention, until he had himself practically and commercially worked the process, and produced by it both iron and steel of a quality which could not be surpassed by any specimens of those metals made by tedious and expensive processes now in general use. The want of success which attended some of the early experiments, was accounted for by practical iron makers in various ways. The majority contended that the metal was burnt or destroyed by the excessive temperature it acquired in the process. Others declared that the metal was too dry, and that it could never become tough or fibrous except by a plentiful admixture of cinder; while a third section traced every fault to the crystalline condition of cast metal, which, they said, could never become tough or capable of bending safely after having once been in a fluid state. Either of these supposed causes of failure would, if well founded, have sufficed to utterly destroy the whole value of the process. Objections of so grave a character, vehemently urged by practical iron-makers, were sufficient to damp the energy of the inventor, who saw that his only hope of success lay in the proof that these practical men were wholly in the wrong. Mature reflection, however, convinced him that the objections so advanced were groundless, and that the reasons assigned had nothing whatever to do with the failure in those cases where failure had ensued. The practical men had learned from long experience that when masses of tough fibrous iron were kept for a long period of time at a high temperature, the metal would gradually assume a crystalline texture and become what is termed burnt iron. Applying this isolated fact, therefore, to the new process, he arrived at once at the conclusion that the high temperature of the iron during the Bessemer process produced the same result, without taking into consideration the fact that the metal in the Bessemer process was a fluid, and, in that condition, it was wholly unaffected by any law of crystallisation, and that the pouring of such metal into a cold cast-iron mould, and its consequent solidification in one or two minutes afforded no time for the formation of large and well-defined crystals, which can only result from a slow aggregation of atoms, as in large forgings, where the time allowed for the development of the crystals varies, say from 100 to 500 hours, whereby the planes of cleavage of the mass are so perfectly marked as to form lines of separation, and, consequently, of weakness in the metal.

"As to the second objection—the impossibility of producing a tough, strong, or fibrous iron, without an admixture of cinder—this is a similar error. It will be readily understood that puddled iron may easily become too dry, that is, the separate granules may become coated with a dry hard scale, such as is produced by heating an iron bar to redness. Pieces of iron so oxidised would not adhere together, but if a little sand be thrown on to the surface so oxidised, a fluid silicate of iron or 'cinder' will be formed. If pressure be then applied to two or more surfaces of highly heated iron coated with this fluid, the latter will be displaced, and the metallic surfaces coming into actual contact, an union will be effected. It will be obvious, however, that these facts in no way apply to metal formed into a mass while fluid, there being no oxidised surfaces to prevent the uniform and perfect cohesion of every particle of the whole mass.

"The third objection—that iron once rendered fluid could never become tough and capable of bending—is wholly disproved by the samples produced, which sufficiently show the enormous amount of strain which iron rendered crystalline by fusion only is capable of sustaining without rupture. It must be borne in mind that the fracture of rolled metal does not necessarily show this so-called fibrous condition; for if a perfect and equal amount of cohesion exists among all the particles of the mass, the fracture will follow the line of force, and the bar will break in nearly a straight line through the smallest part. The long, jagged, irregular fracture which takes place on breaking puddled iron, is only an additional proof of its weakness and want of uniformity of texture, produced chiefly by the diffusion of cinder throughout the mass, giving to it a flaky or lamellar texture, and lessening its cohesion.

"Chemical investigation soon pointed out the real source of difficulty. It was found that although the metal could be wholly decarbonised and the silicon be removed, the quantity of sulphur and phosphorus was but little affected. As different samples were carefully analysed, it was ascertained that the red-shortness was always produced by sulphur, when present to the extent of one-tenth per cent, and that cold-shortness resulted from the presence of a like quantity of phosphorus. It therefore became necessary to remove these substances. Steam and pure hydrogen gas were tried, with more or less success, in the removal of sulphur, and various fluxes, composed chiefly of silicates of the oxides of iron and manganese, were brought in contact with the fluid metal during the process, and the quantity of phosphorus was thereby reduced. Many months were thus consumed in laborious and expensive experiments, a few steps in advance were gained, and many valuable facts were elicited. New patents and new apparatus followed in due course, when it was happily suggested that if it were possible to obtain some comparatively pure pig-iron, free, or nearly so, from sulphur and phosphorus, a proof would at once be given of the correctness of the views entertained with reference to these substances. Such a specimen of iron being procured, it was found that steel of a fair average quality could be readily made from it. Indian and Nova Scotia iron were now tried, and no doubt was then entertained of the value and ultimate success of the process. The results thus obtained caused a total change in the direction in which the efforts of Messrs. Bessemer and Longsdon were directed. It was determined by them at once to import some of the best pig-iron from Sweden, from which iron and steel of excellent quality were made, and the produce was used for almost every purpose for which the highest qualities of steel are employed. It was then decided to discontinue for a time all further experiments, and to erect steel works at Sheffield for the express purpose of fully developing and working the new process commercially, and thus correcting and setting at rest the erroneous impressions that were generally entertained with reference to the invention.

" In manufacturing tool steel of the highest quality, it was found preferable, for several reasons, to use the best Swedish pig-iron, and when converted into steel by the Bessemer process to pour the fluid steel into water, and afterwards to re-melt the shotted metal in a crucible, as is at present practised with blister-steel, by which system the small ingots required for this particular article are more perfectly and more readily made. The production of first class steel by the new process, although a matter of deep interest in one of the smaller branches of the iron trade, still left untouched that great source of this country's prosperity—the manufacture of malleable iron. It was, therefore, impossible to rest content without accomplishing this the original object of the invention. On examining into the stores of mineral wealth so abundant in these islands, it was found that iron ore of the requisite purity existed in vast and apparently inexhaustible beds; that of hæmatite alone as much as 970,000 tons were raised annually, and that a demand only was required to double or treble that quantity. There are also extensive beds of spathose, white carbonate, and magnetic ores of a quality unrivalled in the whole world. Although these superior ores may not lie in the immediate centres of the coal and iron works, yet the vast network of railways which now spreads over the whole breadth of the land may be made available for their transit, and thus not only the most valuable ores may be supplied to the iron works, but the traffic will be a source of profit to those carrying establishments which at present apparently yield only a small return for the capital employed in their construction. When the richness of some of these ores, and the facility with which they may be obtained by open workings from beds of 20 to 30 feet in thickness are considered, it will be obvious that the cost of the pure ore will, even when paying the cost of carriage, very little, if at all, exceed the cost of the inferior ores at present in general use. As 1 ton 12 cwts. of hæmatite will yield 1 ton of pig-iron, and require 60 per cent less lime and 20 per cent less fuel for its reduction than common iron-stone, and that, instead of a weekly yield of 160 to 180 tons, the blast furnace, with hæmatite ore, yields from 220 to 240 tons of pig-iron, it would appear that the pure kinds of iron may be thus obtained at even a less cost than that incurred in the production of the inferior qualities now usually made. The gun and most of the other large specimens exhibited, are made from hæmatite ore, smelted with coke, by the Workington Iron Company, where excellent pig-iron is produced for conversion into malleable iron or steel by the Bessemer process.

"At the Cleator Moor, the Weardale, and the Forest of Dean Iron Works, excellent iron for this purpose is produced. There are, doubtless, many other establishments where, by a slight change only in the furnace charges, there could be produced iron of the requisite quality. In proof of this it may be remarked that the Workington Iron Company, who were producing an article wholly unfit for the purpose, succeeded at once by a variation of their furnace charges (suggested by Mr. Bessemer) in producing a quality superior to several samples of foreign charcoal iron. Thus, then, there is opened in this country an almost inexhaustible supply of raw material, suitable for the production of malleable iron and steel by the Bessemer process, and within easy communication by rail with the iron districts. It may, therefore, be interesting to show in what manner that process may practically be carried into operation.

"A pear-shaped form of the converting vessel has been found most convenient. The vessel is mounted on axes, or near its centre of gravity. It is constructed of boiler plates, and is lined with fire-brick, road drift, or ganister (a local name in Sheffield for a peculiar kind of powdered stone) which resists the heat better than any other material yet tried, and has also the advantage of cheapness. The vessel having been heated is brought into a horizontal position, so that it may receive its charge of melted metal, without either of the tuyeres being below the surface. No action can therefore take place until the vessel is made to assume the vertical position. The process is thus in an instant brought into full activity, and small though powerful jets of air spring upward through the fluid mass. The air expanding in volume divides itself into globules, or bursts violently upwards, carrying with it some cwts. of fluid metal, which again fall into the boiling mass below. Every part of the apparatus trembles under the violent agitation thus produced, a roaring flame rushes from the mouth of the vessel, and as the process advances, it changes its violet colour to orange, and finally, to a voluminous pure white flame. The sparks, which at first were large, like those of ordinary foundry iron, change to small hissing points, and these gradually give way to soft floating specks of bluish light, as the state of malleable iron is approached. There is no eruption of cinder as in the early experiments, although it is formed during the process; the improved shape of the converter causes it to be retained, and it not only acts beneficially on the metal, but it helps to confine the heat, which during the process has rapidly risen from the comparatively low temperature of melted pig-iron, to one vastly greater than the highest known welding heat, by which malleable iron only becomes sufficiently soft to be shaped by the blows of the hammer; but here it becomes perfectly fluid, and even rises so much above the melting point as to admit of its being poured from the converter into a founder's ladle, and from thence to be transferred to several successive moulds. The thin shell or skull of the ladle exhibited shows the extreme fluidity of the metal, and also how little of it is solidified in the ladle during the time of casting.

"The oxygen of the air appears, in this process, first to oxidise the silicon, producing silicic acid, and next to seize the carbon which is eliminated, while the silicic acid, uniting with the oxide of iron, obtained by the combustion of a small quantity of metallic iron, thus produces a fluid silicate of the oxide of iron, or cinder, which is retained in the vessel, and assists in the purification of the metal. The increase of temperature which the metal undergoes, and which seems so disproportionate to the quantity of carbon and iron consumed, is doubtless owing to the favourable circumstances under which combustion takes place. There is no intercepting material to absorb the heat generated, and to prevent its being taken up by the metal; for heat is evolved at thousands of points distributed throughout the fluid, and when the metal boils, the whole mass rises far above its natural level, forming a sort of spongy froth, with an intensely vivid combustion going on in every one of its numberless ever-changing cavities. Thus, by the mere action of the blast, a temperature is obtained in the largest masses of metal in 10 or 12 minutes, that whole days of exposure in the most powerful furnaces would fail to produce.

"The changes in the colour and volume of the flame, and the kind of sparks thrown off, afford easy modes of judging of the state of the metal, since these are given off exteriorly, and are not interfered with by the flame of the fuel, as in the puddling furnace. The sound which the metal produces in the suspended vessel affords also a good indication to the workman. Indeed, few processes appeal so strongly to the external senses. All mere judgment on this point has, however, been rendered unnecessary, by the more certain indications of an apparatus, which registers on a dial the exact number of cubic feet of air passed through the metal, whereby the precise degree of hardness of the steel is regulated at pleasure; its quality, in all cases, being dependent on the quantity of air passed through it—other circumstances being alike. When, therefore, the desired quantity of air has passed through the metal, the vessel is turned on its axis and the fluid steel is poured out. It is then received in the casting-ladle, which is attached to the arm of a hydraulic crane, so as to be brought readily over the moulds. The ladle is provided with a fire-clay plug at the bottom, the raising of which, by means of a suitable lever, allows the fluid steel to descend in a clear, vertical stream into the moulds. As soon as the first mould is filled, the plug valve is depressed, and the metal is prevented from flowing until the casting ladle is moved over the next mould, when, by raising the plug, the second mould is filled in a similar manner; and so on, until all the moulds are filled. After the discharge of the vessel, the process should be repeated without delay, since the temperature of the interior of the vessel is greater after the first charge than it was before, and consequently it is in better condition for the process. The vessel may be moved on its axis by suitable gearing, but it is considered preferable to use hydraulic pressure to effect every movement of the crane and of the vessel, so that when operating on from 5 to 10 tons at a single charge, the director of the process can, from a distant point, and with his own hands, effect every movement required, by merely working the handles which turn on, or off, the pressure of the water. He has also charge of the blast cock, whilst the dial for registering the number of cubic feet of air is before him; and thus, by the control of one responsible man, charges of several tons of crude cast-iron may be converted into malleable iron, or into steel, in a few minutes, and be cast into ingots of any desired form and weight, suitable for large shafts, or for rolling into rails, merchant bars, or plates.

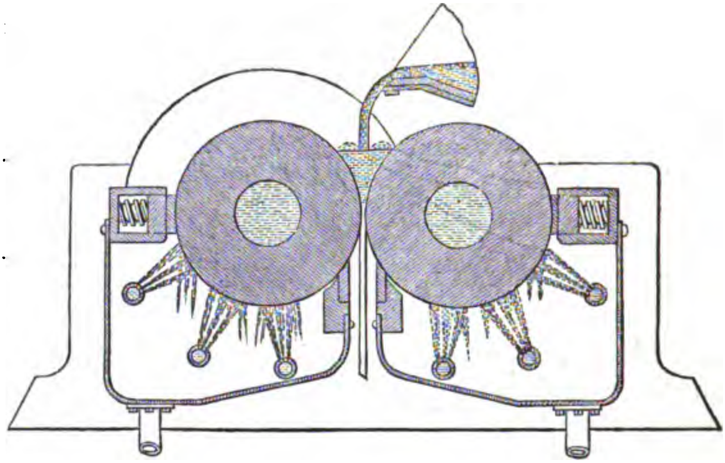
"In the early part of this paper, it was shown that the process of puddling unavoidably introduces into the metal more or less cinder and other mechanically mixed impurities; also that the different degrees of refinement and decarbonisation of the numerous lumps of metal which compose a puddle ball, render the production of a homogeneous mass by that means a desideratum not yet achieved. It has likewise been pointed out how, in the working of the other malleable metals, all these difficulties are avoided by casting the metal in a fluid state into moulds. Now, this is precisely what the Bessemer process proposes to accomplish—that is, to bring malleable iron or steel into the same category with the other malleable metals, and by its purification, in a fluid state, to avoid the diffusion of cinder throughout the mass; so that when cast into ingots or into a single homogeneous mass of any desired form or size, a metal of equal hardness in every part may be produced, without the necessity of welding, or joining of separate pieces. That this can be accomplished is shown by the specimens exhibited. The iron bars of 3 inches square which have been bent and doubled up cold, the twisted bars, and the collapsed cylinders which do not split, but yield like copper to the blow of the hammer, prove this. If assurance be required that there are no hard ribs or sand-cracks, the example of the malleable iron gun, or the iron and steel cylinders, may be taken. With reference to the tensile strength of iron bars or boiler plates so made from English coke pig-iron, the careful testing of plates made of puddled iron, according to Mr. W. Fairbairn, has given an average of 45,300 lbs. per square inch for Staffordshire plates, 45,000 lbs. for Derbyshire, and 57,120 lbs. for Yorkshire plates. Now four examples of the Bessemer iron plate, tested at the Royal Arsenal, Woolwich, according to the report of Colonel Eardley Wilmot, gave an average of 68,314 lbs. or 63,591 lbs. as the least, and 73,100 lbs. as the highest proof for boiler plates ⅜ of an inch in thickness. Here, then, is a result, showing a greater amount of tensile strength above Low Moor, or Bowling iron plates, than those plates possess above the ordinary quality of Staffordshire plates. The bending of the plates of Bessemer iron at acute angles also affords a strong proof of the extreme toughness of the metal, and the application of close punching shows the perfect soundness and homogeneous character of the plate.

"There is another fact, of great importance in a commercial point of view, which must not be overlooked. In the manufacture of plates for boilers and for ship building, the cost of production increases considerably with the increase of weight in the plate. For instance, the Low Moor Iron Company demand £22 per ton for plates weighing 2½ cwts. each, but if the weight exceed 5 cwts. the price per ton rises from £22 to £37. Now with cast ingots such as those from which the Bessemer plates are made, it is less expensive and less wasteful of materials to make plates of from 10 cwts. to 20 cwts. than to produce those of smaller sizes. Indeed there can be little doubt, that eventually large plates will be made by preference, and that those who want small plates will have to cut them from the large ones. A moment's reflection will, therefore, show the great economy of the process in this respect, and when it is remembered that every riveted joint in a plate reduces the ultimate strength of each 100 lbs. to 63 lbs.; the great value of long plates for girders and for ship building will be fully appreciated."

Thus far the author has only considered the manufacture of iron plates of a definite size and from ingots of cast metal, as adopted in the manufacture of copper and other plates. Most metals, it must be observed, at the moment of losing their fluidity, lose their power of cohesion. Malleable iron, however, passes from the fluid into the pasty state, in which it possesses the remarkable and peculiar property of welding. Taking advantage of this well-known peculiarity, Mr. Bessemer has tried the experiment of manufacturing iron, direct from the fluid metal, into endless sheets, in a manner analogous to that by which paper is made of any length.

"In Fig. 23, sufficient of the apparatus is shown to explain

FIG 23.



the principle on which it is constructed. It consists of two rollers of large diameter, placed in the same horizontal plane, with screws to regulate their distance apart. Water is kept constantly passing through the rolls, and from perforated pipes jets of water are projected upwards against their external surfaces in order to keep them cool. The rollers are provided with large flanges, or with suitable stops at their ends, so as to form the space between the rolls on the upper side into a kind of trough, into which the fluid iron is allowed to flow from several small openings formed in a line along the lower part of the casting ladle, so that the rolls form what may be considered an endless mould, with this important difference, that in the ordinary cast-iron ingot mould, a greater or less quantity of air bubbles are formed, and the mass, when cast, is in the ordinary condition of cast metal. The enormous pressure exerted between the rolls, prevents the possibility of any bubbles or cavities being formed. The metal solidifying in the wider part of the space between the rolls, is subjected to great pressure and extension in passing through the narrow part, which the high welding heat and soft state of the metal alone renders possible. The apparatus is capable of producing a plate, the length of which is limited only by the quantity of fluid metal in the ladle. For example, a pair of rolls 3 feet in diameter and 3 feet wide, making five and a half revolutions per minute, will produce in 2 minutes a plate 100 feet long by 3 feet wide, and ⅜ of an inch in thickness, weighing 2 tons. If this system were carried into practical operation, it would be possible to obtain a plate of this size of tough malleable iron without either fuel or manipulation, within 20 minutes after the crude iron had left the blast furnace. This mode of making plates has not yet been tried on a commercial scale; but fluid malleable iron has been poured between a pair of horizontal rolls, and excellent pieces of plate iron have thus been made, which will bear bending and doubling over like the best tin plate, thus affording all the evidence of success that can be derived from a small experiment. A piece of some thin sheets so made with rough pieces of the thin cast metal which formed the skull or coating of the interior of the casting ladle, and which solidified during casting, were examined. These pieces showed clearly the great malleability and toughness of the metal, by the surface they presented when cut through by the shears, and by their folding up without tearing or breaking. On examining these pieces, it was evident that such metal does not require much rolling, and there is reason to hope that the rolling of fluid iron will, on a large scale, produce plates of tough and perfectly homogeneous metal. It must be observed that the skull of the ladle and the other scrap made in the process are very easily worked up. Some pieces, cut from the skull of the ladle were made into a pile at Woolwich, and were drawn down under the hammer at one heat, to a bar 1 inch square; two samples of this bar, when tested, gave a mean tensile strength of 75,897 lbs.

"Iron plates demand the first attention, since they, at present, form the staple manufacture; but it will be understood that there is no difference whatever in the treatment of crude iron by the Bessemer process for producing steel, except that the blast of air is continued for a shorter period. The loss of metal is also about 8 per cent less than on iron. It is, therefore, highly probable that the cheaper material—steel—will ultimately supersede the use of iron, since the tensile strength of steel is nearly double, and its elasticity is much greater than that of iron. The applicability of cast-steel plates to the construction of steam boilers, is fully demonstrated by the soft cast-steel manufactured for this purpose by Messrs. Howell and Shortridge, of Sheffield. It is already extensively used for that purpose, and the extreme toughness of this soft cast-steel is shown by the facility with which it is drawn into tubes; a piece of one of these tubes can be folded up at one end like a piece of paper. It is impossible to look at this sample of tough homogeneous steel without being reminded of the general, but very erroneous, opinions which prevail respecting the brittleness of cast-steel. This is evidently an ancient prejudice, dating from the earliest introduction of that article, when iron bars were double converted in order that the cast-steel made therefrom might be more easily melted. The idea of its brittleness has, however, still clung to it through all the successive improvements in its manufacture.

"At a time when the manufacture of ordnance occupies so large a share of public attention, it may be interesting briefly to point out the great facility which the Bessemer process affords of forming masses both of malleable iron and of steel, of a size suitable for the heaviest ordnance, without any welding together of separate slabs, or the more costly mode of building up the gun with pieces accurately turned and fitted together. Many attempts have been made to produce wrought-iron ordnance, and this object has been successfully accomplished in the case of the large gun produced at the Mersey forge. But, however perfect this one gun may be, the time required to make it, and its immense cost, manifestly leave it still a desideratum to produce guns rapidly and cheaply, of a material equal to, or greater in tensile strength, than wrought-iron; and, if possible, free from the liability which that material has to flaws, and to deterioration during its long exposure to welding heat. It is believed that the Bessemer process supplies this desideratum, for masses of cast-steel can be produced of 10 or 20 tons in weight in a single piece, and two or three such pieces may be conveniently made, by the same apparatus, in one day. The metal so made may be either soft-malleable iron or soft steel. Ordnance may also be cast of malleable iron, with a steel lining or core, or the steel lining may be afterwards fitted to it, so as, in either case, to obtain in the compound mass the hardness and power of one material to resist abrasion, and the tenacity inherent in the other material. In order to show the extreme toughness of such iron, and to what a strain it may be subjected without bursting, several cast and hammered cylinders were placed cold under the steam hammer, and were crushed down without the least appearance of tearing of the metal. Now these cylinders were drawn down from a round cast-iron ingot, only 2 inches larger in diameter than the finished cylinder, and in the precise manner in which a gun would be treated. They may, therefore, be considered as short sections of an ordinary 9-pounder field-gun. Iron so made requires very little forging; indeed the mere closing of the pores of the metal seems all that is necessary. The tensile strength of the samples, as tested at the Royal Arsenal, was 64,566 lbs. per square inch, while the tensile strength of pieces cut from the Mersey gun gave a mean of 50,624 lbs., longitudinally, and 43,339 lbs. across the grain, thus showing a mean of 17,550 lbs. per square inch in favour of the Bessemer iron.

"If it be desired to produce ordnance by merely founding the metal, then the ordinary casting process may be employed, with the simple difference that the iron, instead of running direct from the melting furnace into the mould, must first be run into the converting vessel, where, in from 10 to 20 minutes, it will become steel or malleable iron, as may be desired, and the casting may then take place in the ordinary way.

"The conical ingots being cast in iron moulds, the great delay of moulding in loam will be avoided, and as the iron moulds may be removed from the casting pit within an hour after the metal has been poured into them, the tedious interval of three days, now required by the cast-iron guns before removal, will be avoided, thus immensely increasing the capability of foundries. If it be assumed that these advantages are about equal to the cost of hammering the cast ingots, then, by this process, it would be practicable to produce guns of any size in hammered cast-steel or malleable iron ready for the boring mill, at the same cost as the cast-iron guns now in use, but if the weight of the guns be reduced 20 or 25 per cent in consequence of their superior strength, then an actual saving in that proportion will be effected in the first cost of every gun so made. These facts have been laid before the Government, and their advantages are believed to be fully appreciated by Colonel Eardley Wilmot, the late Superintendent of the Royal Gun Factories, who evinced a great interest in the progress of the invention from its earliest date, and to whose kindness the author is indebted for the many valuable trials of the tensile strength of the various samples of metal that have been submitted for investigation."

At the Birmingham meeting of the British Association for the Advancement of Science in 1865, a paper was read on the value of manganese in producing a superior steel, and the discovery of its value in the Bessemer process, from which we give the following extract* :—

"In 1839 the trade of Sheffield received an enormous impulse from the invention of Josiah Marshall Heath, who patented in this country the employment of metallic manganese, or, as he called it, 'carburet of manganese.' The addition of a small quantity of this metal, say from ½ to 1 per cent, rendered the inferior coke-made irons of this country available for making cast-steel. It removed from these inferior qualities of iron their red-shortness, and conferred on the cast-steel so made the property of welding and working soundly under the hammer. This invention was of immense importance to the town of Sheffield, where its value was at once appreciated. Mr. Heath, supposing himself secure in his patent, told his licensees that if they put oxide of manganese and coal tar or other carbonaceous matter into their crucible along with the blister steel, that it would do as well, and be much cheaper than the carburet of manganese he was selling them. In effect it was the same thing; for before the steel was melted the carbon present reduced the oxide of manganese to the metallic state, so that his patent carburet of manganese was formed in the crucible in readiness to unite with the steel as soon as it became perfectly fused. But the law decided that this was not Heath's patent, and so the good people of Sheffield, after many years' of litigation, were allowed to use it without remuneration to the inventor.

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* URE's Dictionary of Arts and Mines, vol. iii., 777.

"Manganese has now been used for many years in every cast-steel works in Europe. It matters not how cast-steel is made, since manganese added to it necessarily produces the same beneficial changes. No one better appreciated this fact than the unfortunate Mr. Heath, as evidenced by his patent of 1839, in which he declares that his invention consists in the use of carburet of manganese in any process whereby iron is converted into cast-steel. Had Heath seen in his own day the Bessemer process in operation, he could not have said more. He well knew the effect produced by manganese on steel, and, therefore, claimed its employment in any process whereby iron is converted into cast-steel.

"When this patent of Heath's expired and became public property, coupled with the universal addition of manganese and carbon to cast-steel, it would naturally be supposed that the author, in common with the rest of mankind, would have been allowed to share the benefits which Heath's invention had conferred on the whole community, but it was not so.

"The reading of the author's paper at Cheltenham in 1856 was, by the powerful agency of the press, communicated in a few days to the whole country. Great expectations of the value of the new process were formed, both by scientific and practical men, in proof of which it may be stated that licenses to manufacture malleable iron under the patent, were purchased by iron-masters to the extent of £25,000 in less than twenty-five days from the reading of the Cheltenham paper. Great excitement existed at that moment in the iron trade, and many persons seemed to covet a share in an invention that promised so much. There was, consequently, a general rush to the patent office, each one intent on securing his supposed improvement. It was thought scarcely possible that the original inventor should, at the very outset, have secured in his patents all that was necessary to the success of so entirely novel a system; he must surely have overlooked or forgotten something, perhaps even left out all mention of some ordinary appliance too well understood to really need mentioning; so in the jostle and hurry to secure something, any point on which a future claim could be reared was at once patented. Some of these gentlemen even re-patented portions of the writer's own patents, while others patented things in daily use, in the hope that they might be considered new when added to the products of the new process.

"Within six weeks of the date of the Cheltenham paper, various patents for the use of manganese, in the manufacture of iron and steel were taken out, which, at the expiration of three years, however, were allowed to elapse and become public property.

"The author has, therefore, used without scruple any of these numerous patents for manganese, without feeling an overwhelming sense of obligation to the patentee.

"At Mr. Bessemer's suggestion, works for the production of manganese alloys were erected by Mr. Henderson at Glasgow.

"The mode of manufacture consisted in mixing carbonate of manganese (a substance obtained in soda works as one of the products of the manufacture of bleaching powder) with an almost equal quantity of a pure calcined iron ore drawn from a copper works, in which it formed a kind of refuse. Those copper works treat a kind of iron and copper pyrites from the south coast of Spain. The ore is first calcined, and the evolved sulphurous acid used for the production of sulphuric acid; the residue is then roasted with common salt and extracted by means of hot water, thus removing the copper in a dissolved state, and oxide of iron will then remain, which is said to be purified from all its admixtures, and in a state of mechanical aggregation which makes it very suitable for reduction. This oxide of iron now, together with carbonate of manganese, is mixed with charcoal powder or coke dust, and heated in crucibles in the Siemens's furnace.

"The manufacture of this ferro-manganese has at present been given up again.

"Mr. Prieger, of Prussia, has likewise manufactured ferro-manganese by heating mixtures of pyrolusite, charcoal, and finely divided scrap-iron in crucibles from 30 to 50 lbs. weight to a white heat. The alloys contain from 66 to 80 per cent of manganese.

"The Bessemer steel* is in no case more important than in the construction of ships, for in no instance are strength and lightness more essential.

"The Bessemer cast-steel made for ships' plates by the several eminent firms now engaged in that manufacture, is of an extremely tough and ductile quality, while it possesses a degree of strength about double that of the inferior kind of iron plates usually employed in shipbuilding; hence it is found that a much less weight of material may be employed, and, at the same time, a greater degree of strength may be given to all parts subjected to heavy strains.

"Most prominent among the builders of steel ships is the firm of Jones, Quiggin, and Co., Liverpool, who have now constructed no less than 31,510 tons of shipping, wholly or partially built of steel. Of these, thirty-eight vessels are propelled by steam, with an aggregate of 5910 horse-power; besides this, the principal masts and spars of eighteen sailing ships have been made by them wholly of steel.

"Vessels of a large size, constructed to Class A 1, twelve years at Lloyd's, weigh, when built of iron, about 12 cwts. per ton measurement, whereas similar vessels built of steel weigh only about 7 cwts. per ton measurement; thus an iron ship, to take first class at Lloyd's for 1000 tons measurement, would weigh 250 tons more than a steel one of the same class. Such a vessel could, therefore, take 250 tons or 25 per cent more freight at the same cost, and could avail herself of the difference of immersion to leave or enter port when the tide would not permit an iron vessel to do so. As a steamer she would carry 250 tons more of coal, and thus be enabled to lengthen her voyage or take her coal for the return trip. The two steel paddle-wheel steamers which were built at Liverpool by the Messrs. Jones & Co., for the Dublin and Liverpool service, will draw from 3 to 4 feet less water than iron steamers built on the same lines, and being thus enabled to leave port at all states of the tide, will not require a tidal train in connection with them. If the employment of steel for the construction of merchant vessels is found to be so important, how much more so is it for ships of war. Some of the larger class of armour plated vessels require 6000 tons of iron for their construction, and an addition of 1800 tons in the shape of 4½-inch armour plates. Now, if the frames and inner skin of such a vessel were constructed of steel, it would be much stronger even if reduced to 4000 tons in weight; this would admit of 9-inch armour plates being used in lieu of 4½-inch, and would still leave the vessel 200 tons lighter than the present ones, and hence, as the resistance of the armour to impact, is as the square of the thickness of the plate, we should have a vessel capable of resisting four times the force of those at present constructed, while it would be 200 tons less in weight.

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* URE's Dictionary of Arts and Mines, vol. iii., 779.

"The application of steel for projectiles has now become a necessity since the introduction of armour plates. We have now used 110 lbs. shot, and these have passed with very slight injury through a 5-inch armour plate. Specimens of bent angle iron, made of Bessemer iron, and rolled at the Millwall Iron Works, in London, and from the same works a portion of one of Hughes's patent hollow-steel beams, for supporting the armour plating in course of construction for the forts at Cronstadt, are interesting examples of what the rolling mills of the present day can effect, and of the facility with which cast malleable iron and cast-steel admit of being worked into the most difficult forms.

"There is no department of engineering in which the peculiar toughness of steel and its strength and power of resisting wear and abrasion are of such vital importance as in the application to railway purposes. This fact had long since impressed itself strongly on the mind of Mr. Ramsbottom, of the London and North Western Railway, who commenced experiments with this material in 1861, carefully though trustingly, he tried it step by step, not even at first venturing to employ it for passenger trains, but as proofs of its safety and economy crowded upon him, he carefully, applied it to the most important parts of passenger engines, and even to the manufacture of the formidable engine cranks (at that time entrusted only to the most eminent iron-making firms in the kingdom); these iron cranks are now being replaced by steel ones forged from a single mass. One of these steel cranks, manufactured at the new steel works at Crewe, was regarded as a remarkably good illustration of the use of steel for this purpose; that gentleman has also taken out of use a plain steel axle that has run a distance of 112,516 miles and now exhibits very slight signs of wear.

"The tires of wheels, on which so much of the public safety depends, were then tried, but the exact amount of difference between the endurance of wrought-iron and Bessemer steel for this purpose, is not yet ascertained, as none of these steel tires are yet worn out, but enough has been shown to prove the advantage of entirely replacing iron by steel for this purpose.

"In order to show how a steel tire will resist the most violent attempts to produce fracture, an example is given of a steel tire manufactured by Messrs. Bessemer and Co., of Sheffield; it was placed on edge under a 6-ton steam hammer and subjected to a series of powerful blows until it assumed its present form—that of a figure of eight, a degree of violence immensely more than it could ever be subjected to in practice. These tires are made without weld or joint by forging them from a square ingot, partly under the improved plan invented by Mr. Ramsbottom, and partly by an improved mode of flanging and rolling, invented by Mr. Allen, of the Bessemer Steel Works, Sheffield.

"So important were found to be the advantages of employing cast-steel as a substitute for wrought-iron at the works of the London and North-Western Railway Company, that the directors, acting under the advice of their able engineer, determined on building a large steel works at Crewe, which is now in active and successful operation. In the design and arrangement of their plant for working up the steel, several important improvements have been introduced by Mr. Ramsbottom—among others his duplex hammer, which strikes a bloom on both sides of the ingot at once in a horizontal direction, and thus renders unnecessary the enormous foundations required for ordinary hammers. Here, also, he has put up his improved rolling mill for rolling blooms of large size, the enormous machine being reversed with the greatest rapidity and ease by the attendant, without any shock or concussion whatever.

"While matters were thus steadily progressing in the engine department of the company, the engineer of the permanent way, Mr. Woodhouse, took in hand a thorough investigation of a no less important problem, viz., the substitution of cast-steel for wrought-iron railway bars. For this purpose some 500 tons of rails were made and put down at various stations where the traffic was considerable, so as to arrive, at the earliest period, at a true comparison of the respective endurance of wrought-iron and cast-iron steel rails. It will be unnecessary to enter into the numerous details of the extensive series of experiments systematically carried out by Mr. Woodhouse; the trials made at Camden Town will suffice to show the extraordinary endurance of steel rails. It is supposed that there is not one spot on any railway in Europe where the amount of traffic equals that at the Chalk-farm bridge at Camden Town. At this spot there is a narrow throat in the line, from which converges the whole system of rails employed at the London termini of this great railway. Here all passenger, goods, and coal traffic have to pass; here, also, the making-up of trains and shunting of carriages is continually going on. At this particular spot two steel rails were fixed on May 2nd, 1862, on one side of the line, and two new iron rails were on the same day placed precisely opposite to them, so that no engine or carriage could pass over the iron rails without passing over the steel ones also. When the iron rails became too much worn to be any longer safe for the passage of trains, they were turned the other way upwards, and when the second side of the iron rails were worn as far as the safety of the traffic would allow, the worn-out rail was replaced by a new iron one—the same process being repeated as often as was found necessary. Thus we find, at the date of the report on March 1st, 1865, that seven rails had been entirely worn out on both faces. Since then another rail has been worn out up to July, making sixteen faces worn out, the seventeenth face being in use on August 22nd, when the steel rail that had been placed opposite to them was taken up. The first face of the rail only has been used, and this has now become much thinner than it was originally, but, in the opinion of the platelayers, is still capable of wearing out another half dozen faces. Taking its resisting powers at three more faces only, it will show an endurance of twenty to one in favour of steel.

"Mr. Woodhouse has ascertained, by careful and continued testing for 24 hours at a time, that an average of 8082 engine tenders or carriages pass over the steel rails every 24 hours, equal to 16,164 wheels every day for 1207 days, making a total of 9,754,974 wheels passed over the rail. Subject to this excessive wear, the rail appears to have been reduced 7½ lbs. per yard; hence for every grain in weight of steel lost by abrasion, no less than 371 wheels had to pass over it. Another steel rail, put down also in May 1862, at a place much less subject to wear, has had four faces of iron rails worn out opposite to it, and still appears as if very little used. An iron rail wears out by giving way at various parts of the imperfectly welded mass, and not by the gradual loss of particles of metal, as in the case of the steel rail, which no amount of wear and tear seems capable of disjointing. It must be borne in mind that this enormous endurance of cast-steel is not owing to its hardness or brittleness, as some have supposed, for, in fact, Bessemer steel possesses an extreme degree of toughness. To prove this, one of the same quality of steel rails having been attached at one end to the main driving shaft of a steam engine so as to twist it while cold into a long spiral, measuring 9 feet in length at the top and bottom, and only 6 feet if measured along the centre of the web. This behaviour of the rail will dispel any idea of brittleness that may have been entertained."

## HEATON'S PROCESS.

Heaton's process differs from Bessemer's in that it employs nitrate of soda as the oxidising agent instead of atmospheric air, and that it treats impure pig-iron as well as the purer kinds of pig, while Bessemer's process is exclusively confined to the latter. It furthermore produces steel and wrought-iron in a pasty state, as is done in the puddling process, whilst Bessemer's process yields steel and wrought-iron in a thinly liquid state, which circumstances give it a decided advantage over that of Heaton. Both processes aim at the conversion of large masses at a time.

Mr. Heaton affirms that, for the following reasons, his process possesses an advantage of several pounds sterling per ton over any other:—

1. It deals with the cheapest raw material.
2. It produces steel direct from pig-iron.
3. Whereas the plant necessary for the production of steel and wrought-iron by other processes is enormously expensive, steel is produced by his patented process at an exceedingly low cost, and with an insignificant outlay of capital. The cost of the necessary plant, including patent converting apparatus, capable of producing from a series of four converters 80 tons of crude steel per 12 hours, is under £1000.
4. The cost of maintenance of the plant is very trivial.
5. The waste of metal in conversion is reduced greatly below that of any other known process. The slag produced may be utilised on the works, and forms the subject of a new and valuable patent.

6. The process being chemical and not mechanical, the labour and expenditure involved in the carrying out of the puddling process are entirely dispensed with.

7. The process of conversion is simple, rapid, and certain, the conversion of pig-iron into steel being effected in a few minutes.

8. The results obtained are remarkable for their uniformity.

Dr. Robert Mallet, F.R.S., in his preliminary report says that " Heaton's patent process constitutes, both with respect of economy of production and utilisation of inferior pig-iron, one of those metallurgic advances which leave their mark indelibly on great national industries."

We do not hesitate to endorse Dr. Mallet's judgment, although, at the same time, we do not fail to apprehend the great difficulties which Heaton's patent process will still have to overcome, and although we are able, at present, to judge only from experiments, and not from a production carried on on a large scale.

Heaton's process has been brought before the public only a short time, and it has been received with the same distrust which Bessemer's process met with on its first introduction, although the latter is now universally acknowledged to be a decided and confirmed success. Mr. Bessemer confesses himself that at the time when he first submitted his process to the British Association at Cheltenham in 1856, it was in such an early stage of development, as to require much labour and great expenditure of time and money in order to yield commercial results, and that the important system of manufacture to which it gave rise, would, to this hour, have been wholly unknown if the paper at Cheltenham had not been read. Mr. Bessemer then developed the process in his steel works at Sheffield, which he erected for the purpose, and he was greatly assisted in his endeavours by the scientific investigations on the conduct of the process which were made at Edsken in Sweden.

Heaton's process also requires similar development, and as it is based on sound scientific principles, it can hardly fail to meet with corresponding success. The Bessemer process has, in one point, fallen short of the expectations formed of it, namely, that it cannot replace the puddling process; this we expect Heaton's process will do, though, on the other hand, the latter when carried on with impure pig-iron will not, perhaps, admit of the production of the superior sorts of tool steel.

Heaton's process is carried on in apparatus which are represented in Figs. 24 to 30 of Heaton's steel plant of Langley Mill Steel and Iron Works, near Nottingham.

FIG. 24.

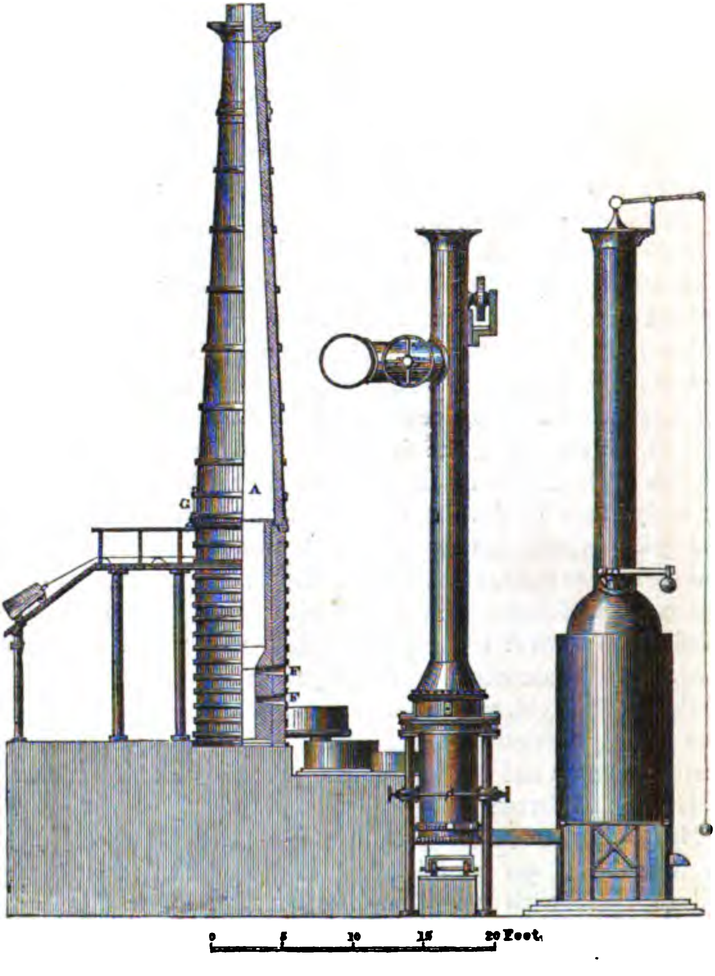
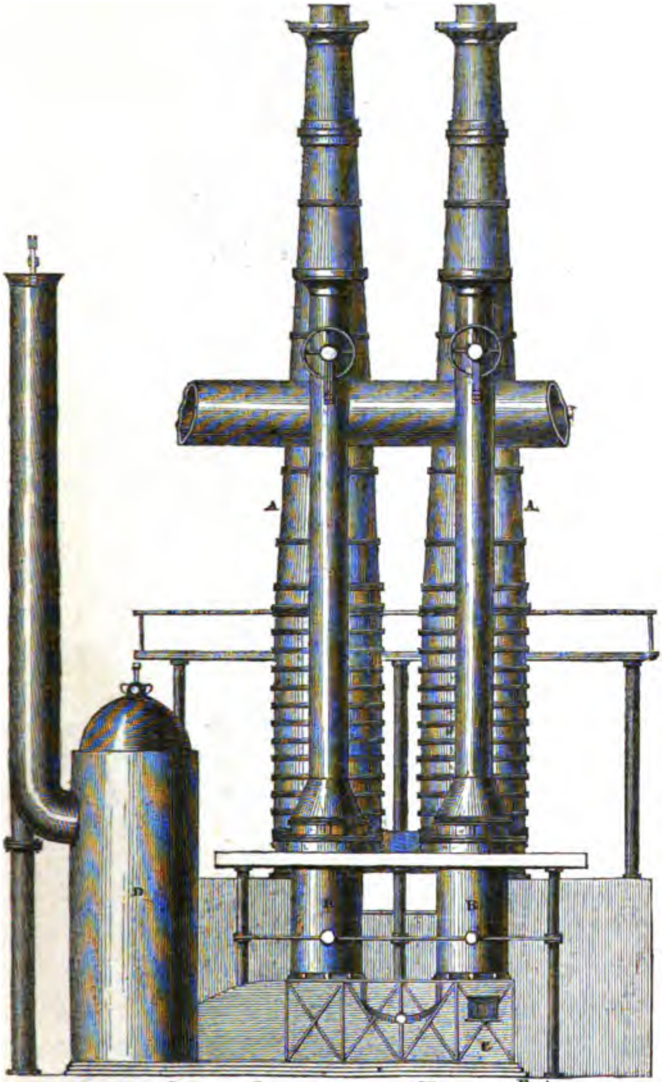


Fig. 24 is a side view of the apparatus, showing also a vertical section of one-half of the cupola. Fig. 25 is a front view, and the same letters refer to the same parts in both

FIG. 25.



views. Figs. 26, 27, 28, and 29 show different parts of the apparatus in plan. The cupola furnaces, A, A, in which the metal is melted are constructed with a high chimney stalk at their top. The chimney causes draught to supply the furnace with air through the tuyeres, F, F, and this action is somewhat similar to that of the Woodward cupola, where the draught is caused by a steam jet. G is the opening through which the cupola is charged with metal and coke from a platform with an inclined tramway leading to it. B, B are the converters into which the melted lead is run direct from the cupola, and from which the melted crude steel may be transferred into the reverberatory furnace. The converter, a section of which is shown in Fig. 30, is nearly a cylindrical cupola, lined with 4½-inch fire-brick, the shell of boiler plate, and surmounted by a plate-iron conical cap

FIG. 26.

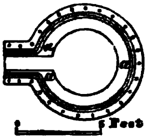


FIG. 27.

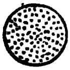


FIG. 28.

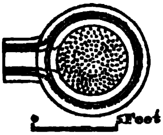
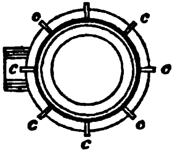
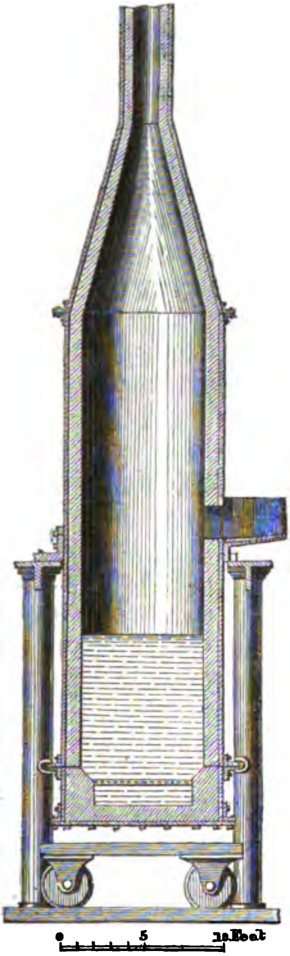


FIG. 29.



and narrower cylindrical flue provided with means for the escape of the gases. The converter may be supposed to be cut horizontally in two parts at about one and a half diameters

FIG. 30.



in height, the bottom part being rendered movable and capable of being withdrawn on wheels without disturbance to the supports, &c., of the remaining upper portions of the converter. Provision is made for the temporary attachment of the two parts by clamps and cotters. At one side of the fixed cylindrical part of the converter, a sort of hopper with a loosely hinged iron plate cover is provided, which communicates with the cavity within.

The lower part or "converting pot" has a cylindrical cavity with a flat bottom, and with the sides near the top edge sloping inwards to a cone all round. The cavity, up to the level of the lower edge of this cone, is prepared to hold just the bulk of crude nitrate of soda required for the volume of liquid iron to be operated on, and for the iron when converted; the converting pot is lined with fire-brick and refractory clay. When the crude nitrate is filled in and levelled up to the narrow part of the conical lining, or a little beyond it, the perforated cast-iron plate is simply laid upon its levelled surface and worked round a little, until its edges bed firmly into and upon the clay lining. In this state, the converting pot is carried in under the upper part of the converter, clamped up to it, and the whole is now ready for work.

Fig. 26 is a horizontal section of the movable bottom of a converter, showing the fire-brick lining, *a*, *a*.

Fig. 27 shows a perforated metal plate which is placed upon the nitrate of soda. Fig. 28 is a horizontal section of a converter, showing the perforated plate in position. Fig. 29 is a sectional plan of a converter showing the cramps, *c*, *c*, &c., for holding the converting pot up to the cylinder of the converter whilst the process is going on; these cramps are shown also in Figs. 24 and 25. D in Figs. 24 and 25 is a steam boiler, heated with the waste heat from the reverberatory furnace.

Professor Miller, Dr. Mallet, and Mr. Kirkaldy have published reports of the conduct of Heaton's process and its results.

Professor Miller's preliminary report describes the process thus:—

"On the occasion of our (namely, his and Dr. Mallet's) visit to the works of Langley Mill, on the 10th of July, 1868, 6¼ cwts. of Clay Lane pig, No. 4, were charged into a hot cupola which contained no other iron; and immediately

6¼ cwts. of Stanton forge pig, No. 4 (produced from 2-3rds of Northamptonshire brown ore, 1-6th of Chesterfield clay ore, and 1-6th of puddling cinder) was added, and the whole, when melted, was drawn off into a ladle, from which it was transferred to the *converter*.

"The 'converter' is a wrought-iron pot, lined with fire-clay. In the bottom of it was introduced a mixture of 169 lbs. of crude nitrate of soda, 40 lbs. of siliceous sand, and 20 lbs. of air-slaked lime; but these proportions in practice are varied considerably. On the top of this mixture a cast-iron perforated plate, weighing 95 lbs., was placed. The converter was then securely attached to the open mouth of a sheet-iron chimney, and the melted iron from the cupola (sample of this marked No. 4) was poured in.

"In about 2 minutes a reaction commenced; at first a moderate quantity of brown nitrous fumes escaped, these were followed by copious blackish, then grey, then whitish fumes, produced by the escape of steam carrying with it, in suspension, a portion of the flux. After the lapse of 5 or 6 minutes, an intense deflagration occurred, attended with a loud roaring noise and a burst of a brilliant yellow flame from the top of the chimney. This lasted for about a minute and a half, and subsided as rapidly as it commenced. When all had become tranquil, the converter was detached from the chimney, and its contents were emptied upon the iron pavement of the foundry.

"The crude steel was in a pasty state, and the slag fluid; the cast-iron perforated plate had become melted up and incorporated with the charge of molten metal.

"The slag had a glassy, blebby appearance, and a black or dark green colour in mass.

"A mass of crude steel from the converter was then subjected to the hammer (No. 7).

"About 4½ cwts. of the crude steel were transferred to an empty, but hot reverberatory furnace, where, in about an hour's time, it was raised to a welding heat, and forged into four blooms under the steam hammer, then rolled into square billets, which were cut up, re-heated, and rolled into finished bars, varying in thickness from 1 inch to ⅝ of an inch (No. 8).

"Three or four cwts. of the crude steel from the converter were transferred to a re-heating furnace, then hammered into flat cakes, which, when cold, were broken up and sorted by hand for the steel melter (No. 9).

"Two fire-clay pots, charged with a little clean sand, were heated, and into each 42 lbs. of the cake steel were charged. In about 6 hours the melted metal was cast into an ingot (10 B).

"Two other similar pots were charged with 35 lbs. of the same cake steel, 7 lbs. of scrap iron, and 1 oz. of oxide of manganese. These, also, were poured into ingots (10 C).

"The steel, 10 B and 10 C, was subsequently tilted, but was softer than was anticipated.

"These results, on the whole, are to be considered rather as experimental than as average working samples.

"I have, therefore, made an examination of the following samples only:—

No. 4.—Crude cupola pig.
„ 7.—Hammered crude steel.
„ 8.—Rolled steely iron.
„ 5.—Slag from the converter.

"I shall first give the results of my analysis of the three samples of metal:—

| | Cupola Pig. No. 4. | Crude Steel. (7). | Steel Iron. (8). |
|---|---|---|---|
| Carbon | 2·830 | 1·800 | 0·993 |
| Silicon, with a little titanium | 2·950 | 0·266 | 0·149 |
| Sulphur | 0·113 | 0·018 | traces |
| Phosphorus | 1·455 | 0·298 | 0·292 |
| Arsenic | 0·041 | 0·039 | 0·024 |
| Manganese | 0·318 | 0·090 | 0·088 |
| Calcium | — | 0·319 | 0·310 |
| Sodium | — | 0·144 | traces |
| Iron (by difference) | 92·293 | 97·026 | 98·144 |
| | 100·000 | 100·000 | 100·000 |

"It will be obvious from a comparison of these results that the reaction with the nitrate of soda has removed a large proportion of the carbon, silicon and phosphorus, as well as most of the sulphur. The quantity of phosphorus (0·298 per cent) retained by the sample of crude steel from the converter which I analysed, is obviously not such as to injure the quality.

"The bar-iron (No. 9) was, in our presence, subjected to many severe tests. It was bent and hammered sharply round without cracking. It was forged and subjected to a similar trial, both at a cherry red and at a clear yellow heat, without cracking; it also welded satisfactorily.

"The removal of the silicon is, also, a marked result of the action of the nitrate.

"It is obvious that the practical point to be attended to, is to procure results which *shall be uniform*, so as to give steel of uniform quality when pig of a similar composition is subjected to the process. The experiments of Mr. Kirkaldy on the tensile strength of various specimens, afford strong evidence that such uniformity is attainable.

"I have not thought it necessary to make a *complete* analysis of the slag, but have determined the quantity of sand, silica, phosphoric and sulphuric acid, as well as the amount of iron it contains. It was less soluble in water than I had been led to expect, and it has not deliquesced, though left in a paper parcel.

"I found that of 100 parts of finely-powdered slag, 11·9 were soluble in water. The following was the result of my analysis:—

| | |
|---|---|
| Sand . . . . . . . . . . . . . | 47·3 |
| Silica in combination . . . . . | 6·1 |
| Phosphoric acid . . . . . . . . | 6·8 |
| Sulphuric acid . . . . . . . . | 1·1 |
| Iron (a good deal of it as metal) . | 12·6 |
| Soda and lime . . . . . . . . | 26·1 |
| | 100·0 |

"The result shows that a large proportion of phosphorus is extracted by the oxidising influence of the nitrate, and that a certain amount of the iron is mechanically diffused through the slag.

"The proportion of slag to the yield of crude steel was not ascertained by direct experiment, but, calculating from the materials employed, its maximum amount could not have exceeded 23 per cent of the weight of the charge of molten metal. Consequently, the 12·6 per cent of iron in the slag could not be more than 3 per cent of the iron operated on.

"In conclusion, I have no hesitation in stating that Heaton's process is based upon correct chemical principles. The mode of attaining the result is both simple and rapid. The nitric acid of the nitrate in this operation imparts oxygen to the impurities always present in cast-iron, converting them into compounds which combine with the sodium, and these are removed with the sodium in the slag. This action of the sodium is one of the peculiar features of the process, and gives it an advantage over the oxidising methods in common use."

The following is Dr. Mallet's opinion of the reality and commercial value of Heaton's process:—

"This process for converting crude pig-iron into wrought-iron and into steel, by the employment of nitrate of soda, in Heaton's patent converter, has been repeated at Langley Mills many times, in my presence. I have examined minutely into its details as applicable in practice on a large scale, and its results; and I have also considered the chemical researches made as to the materials used and products obtained, by Professor Miller, of King's College, and I have been present at experiments, conducted by Mr. David Kirkaldy, at his Testing Works, at Southwark, as to the physical qualities of the products which were obtained by this process, in my own presence, at Langley Mills. In view of all the facts that have come before me, I can affirm the following as truths established beyond question:—

"1st. That Heaton's patent process of conversion by means of nitrate of soda, is at all points in perfect accord with metallurgic theory. That it can be conducted upon the great scale with perfect safety, uniformity, and facility, and that it yields products of very high commercial value.

"2nd. That in point of manufacturing economy or cost it can compete with advantage against every other known process for the production of wrought-iron and steel from pig-iron.

"3rd. Amongst its strong points, however, apart from and over and above any mere economy in the cost of production, are these :—It enables first-class wrought-iron, and excellent steel to be produced from coarse, low-priced brands of crude pig-irons, rich in phosphorus and sulphur, from which no other known process, not even Bessemer's, enables steel of commercial value to be produced at all, nor wrought-iron, except such as is more or less either 'cold-short' or 'red-short.' Thus, wrought-iron and cast-steel of very high qualities have been produced, in my presence, from Cleveland and Northamptonshire pig-irons rich in phosphorus and sulphur, and every iron-master, I presume, knows that first-class wrought-iron has not previously been produced from pig-iron of either of these districts, nor marketable steel from them at all.

"Heaton's process presents, therefore, an almost measureless future field in extending the manufacture of high class wrought-iron and excellent steel into the Cleveland and other great iron districts, as yet precluded from the production of such materials by the inferior nature of their raw products. It admits of the steel manufacture also being extended into districts and countries where fuel is so scarce and dear that it is otherwise impossible.

"I cannot, in this brief communication, point out the prospects which the employment of this system presents, of greatly diminishing the existing waste of material, fuel, time, and wages, in the puddling process, and of lessening difficulties in relation to labour questions which beset that process, injuriously to the British iron trade. Nor can I adequately point out the large reduction in the original outlay for plant, which this system admits of as compared with any other for equal annual out-put of iron and steel.

"Dr. Miller has proved, incontrovertibly, that the Heaton process does eliminate from the crude pig-iron almost the whole of the phosphorus and sulphur, the trace remaining being unobjectionable in the wrought-iron and steel produced, even when they have been made from the pig-irons known to be the richest in these injurious constituents of any make in Great Britain.

"The wrought-iron made in my presence from Cleveland and Northampton pigs, and tested for tensile resistance also before me, bore a rupturing strain of 23 tons per square inch, and an elongation of nearly ¼ of the original unit in length. It is therefore iron of great strength and toughness, and yet probably by no means the very best that this process is capable of producing hereafter. It possesses those qualities which best fit iron for artillery, armour plates, and iron ships or boilers.

"The tilted cast-steel also made in my presence, from the very same pig-irons as the above, bore a tensile strength at rupture of above 42 tons per square inch with an elongation of 1-12th of the unit of length. It is, therefore, a remarkably tough and fine quality of steel, well suited for rails, shipbuilding, and all other structural uses. In a word, steel suited for any purpose known to the arts, can be produced by this system from very inferior brands of pig-iron, from such as by no other known process could serviceable steel be made at all."

Mr. Kirkaldy has tested not only the bars of steel and steel-iron made in the presence of Dr. Miller and Dr. Mallet, but a number of other bars made by Heaton's process from different brands of pig-iron, The results of these experiments are given in the following tables :—

| DESCRIPTION. | MEAN BREAKING WEIGHT PER SQUARE INCH. | | CONTRACTION OF AREA. | EXTENSION IN 10 INCHES. | APPEARANCE OF FRACTURE. |
|---|---|---|---|---|---|
| | lbs. | tons. | p.c. | p.c. | |
| 1. Hammered cast-steel—made in in the presence of Messrs. Miller and Mallet. Average of 5 samples .. .. | 95,414 | 42·6 | 9·3 | 7·7 | granular. |
| 2. Ditto—made from 13 cwts. *Glengarnock Pig*, No. 2 (Scotch). Average of 2 samples .. .. .. .. | 99,481 | 44·4 | 16·9 | 8·5 | 55 p.c. silky;<br>45 p.c. granular. |

| Description. | Mean Breaking Weight per square inch. | | Contraction of Area. | Extension in 10 inches. | Appearance of Fracture. |
|---|---|---|---|---|---|
| | lbs. | tons. | p.c. | p.c. | |
| Average of 2 samples .. | 84,877 | 37·8 | 3·9 | 4·1 | granular (peculiar). |
| 3. Hammered cast-steel—made of 7 cwts. of *Workington Pig*, No. 1, and 6 cwts. of *Stanton Forge Pig*, No. 4, mixed in the cupola in the usual way. Average of 3 samples .. .. .. .. | 92,961 | 41·5 | 13·9 | 7·6 | granular (the weakest of the 3 sample bars was 75 p.c. silky). |
| 4. Ditto—made from a charge of 13 cwts. of *Round Oak Pig-iron* only; the quantity of nitrate of soda used was 10 p.c. Average of 6 sample bars (0·77 × 0·78) | 90·478 | 40·4 | 1·9 | 1·0 | granular. |
| 5. Ditto—made from a charge of 13 cwts. of *Butterleg Iron*, with 10 p.c. of nitrate of soda; 8 bars were made from the cakes melted in the crucible, and tilted into 4 bars of 1 inch and 4 bars of ½ inch square. Average of 4 bars of ½ in. square .. .. .. .. | 100,019 | 44·7 | 11·4 | 5·5 | granular. |
| Average of 4 bars 1 inch square .. .. .. .. | 85,964 | 38·3 | 3·1 | 2·6 | ditto. |
| 6. Ditto—made from a charge of 13 cwts. of *Dowlais Iron* (No. 2), with 10 p.c. of nitrate of soda; 8 bars were made from the cakes melted in the crucible, and tilted in 4 bars of 1 inch and 4 bars of ¾ inch square. Average of 4 bars ¾ inch square .. .. | 95,470 | 42·6 | 3·2 | 2·5 | granular. |
| Average of 4 bars 1 inch square .. .. .. .. | 82,438 | 36·8 | 2·5 | 1·3 | ditto. |
| 7. Ditto—made from a charge of 13 cwts. of *Dowlais Pig-Iron* (No. 3), with 10 p.c. of nitrate of soda; 12 bars were made from cakes melted in the crucible, and tilted into 4 bars of 1 inch, ¾ inch, and ½ inch square. Average of 4 bars ½ inch square .. .. .. | 112,875 | 50·4 | 7·6 | 2·3 | granular. |

| Description. | Mean Breaking Weight per square inch. | | Contraction of Area. | Extension in 10 inches. | Appearance of Fracture. |
|---|---|---|---|---|---|
| | lbs. | tons. | p.c. | p.c. | |
| Average of 4 bars ¾ inch square .. .. .. .. | 91,096 | 40·7 | 2·9 | 1·2 | granular. |
| Average of 4 bars 1 inch square .. .. .. .. | 79,480 | 35·5 | 2·0 | 0·8 | ditto. |
| 8. Hammered cast-steel—made from a charge of 13 cwts. of *Middlesbro'* (No. 4) *Forge Pig-Iron*, with 10 p.c. of nitrate of soda; 12 bars were made from cakes melted in the crucible, and tilted into 4 bars of 1 inch, ¾ inch, and ½ inch square. Average of 4 bars ½ inch square .. .. .. | 119,699 | 53·4 | 18·3 | 10·3 | granular (peculiar). |
| Average of 4 bars ¾ inch square .. .. .. .. | 99,938 | 44·7 | 5·8 | 4·2 | ditto. |
| Average of 4 bars 1 inch square .. .. .. .. | 96,713 | 43·2 | 5·8 | 4·4 | ditto. |
| 9. Ditto—made from pure *Workington Hæmatite Pig-Iron*, with 7½ p.c. of nitrate of soda; 6 bars ½ in. square made as the other bars before tested. Average of the 6 bars .. .. | 108,489 | 48·4 | 5·8 | 2·7 | granular. |
| 10. Ditto—made from White Forge Pig, produced from oolite ore at the works of Baron d'Adelswärd, at Longwy, Moselle, France. The charges of nitrate of soda were as under. | | | | | |

No. I.

| | cwts. | qrs. | lbs. |
|---|---|---|---|
| Longwy White Forge Pig .. .. .. .. .. | 14 | 2 | 0 |
| Perforated plate, Clay Lane.. .. .. .. .. | 1 | 0 | 0 |
| | 15 | 2 | 0 |
| Nitrate of soda .. .. .. | 1 | 1 | 10 |

No. II.

| | cwts. | qrs. | lbs. |
|---|---|---|---|
| Longwy White Forge Pig .. .. .. .. .. | 14 | 2 | 0 |
| Perforated plate, Clay Lane.. .. .. .. .. | 1 | 0 | 0 |
| | 15 | 2 | 0 |
| Nitrate of soda .. .. .. | 1 | 0 | 26 |

| Description. | | | | Mean Breaking Weight per square inch. lbs. | Mean Breaking Weight per square inch. tons. | Contraction of Area. p.c. | Extension in 10 inches. p.c. | Appearance of Fracture. |
|---|---|---|---|---|---|---|---|---|
| No. III. | | | | | | | | |
| | cwts. | qrs. | lbs. | | | | | |
| Longwy White Forge Pig .. .. .. .. | 14 | 2 | 0 | | | | | |
| Perforated plate, Clay Lane.. .. .. .. | 1 | 0 | 0 | | | | | |
| | 15 | 2 | 0 | | | | | |
| Nitrate of soda .. .. | 1 | 0 | 20 | | | | | |
| No. IV. | | | | | | | | |
| | cwts. | qrs. | lbs. | | | | | |
| Longwy White Forge Pig .. .. .. .. | 14 | 2 | 0 | | | | | |
| Perforated plate, Clay Lane.. .. .. .. | 1 | 0 | 0 | | | | | |
| | 15 | 2 | 0 | | | | | |
| Nitrate of soda .. .. | 1 | 0 | 1¾ | | | | | |
| 12 bars of ¾ inch cast-steel were made from No. 2 and No. 3 charges. Average of 6 bars .. .. .. | | | | 116,339 | 52·0 | 6·3 | 4·0 | granular (peculiar). |
| Average of 6 bars .. .. | | | | 110,864 | 49·5 | 30·1 | 12·5 | granular and silky. |
| 11. Cast-steel, hammered, made from 3 charges of Grey Foundry Iron, produced at the works of M. de Wendel and Co., at Hayange, Moselle, France, from oolite ore, similar to the Northamptonshire ore, with charges of nitrate of soda in the following proportions:— | | | | | | | | |
| No. I. | | | | | | | | |
| | cwts. | qrs. | lbs. | | | | | |
| Hayange Grey Foundry Pig .. .. .. .. .. | 14 | 2 | 0 | | | | | |
| Perforated plate of Cleveland Pig.. .. | 1 | 0 | 0 | | | | | |
| | 15 | 2 | 0 | | | | | |
| Nitrate of soda .. .. | 1 | 1 | 10 | | | | | |
| No. II. | | | | | | | | |
| | cwts. | qrs. | lbs. | | | | | |
| Hayange Grey Foundry Pig .. .. .. .. .. | 14 | 2 | 0 | | | | | |
| Perforated plate of Cleveland Pig.. .. | 1 | 0 | 0 | | | | | |
| | 15 | 2 | 0 | | | | | |
| Nitrate of soda .. .. | 1 | 2 | 2 | | | | | |

| Description. | cwts. | qrs. | lbs. | Mean Breaking Weight per square inch. lbs. | tons. | Contraction of Area. p.c. | Extension in 10 inches. p.c. | Appearance of Fracture. |
|---|---|---|---|---|---|---|---|---|
| No. III. | | | | | | | | |
| Hayange Grey Foundry Pig .. .. .. .. .. | 14 | 2 | 0 | | | | | |
| Perforated plate of Cleveland Pig.. .. | 1 | 0 | 0 | | | | | |
| | 15 | 2 | 0 | | | | | |
| Nitrate of soda .. .. | 1 | 3 | 4 | | | | | |
| The steel bars were made as before stated. Average of 4 bars ⅝ inch square .. | | | | 114,123 | 50·9 | 5·6 | 3·1 | granular (peculiar). |
| Average of 4 bars ½ inch square .. .. .. .. | | | | 112,590 | 50·3 | 5·6 | 3·2 | ditto. |
| Average of 4 bars ¾ inch square .. .. .. .. | | | | 84,740 | 37·8 | 2·6 | 1·3 | ditto. |
| 12. Cast-steel, hammered, made from a charge of 15 cwts. of white forge pig produced from oolite ore at the works of Baron d'Adelswärd, at Longwy, France, treated with 1 cwt. 25 lbs. of nitrate of soda. The 6 bars of steel were made from cakes melted in the crucible, and tilted into ⅝ inch square bars. Average of the 6 bars.. .. .. .. | | | | 109,951 | 49·1 | 8·7 | 6·0 | granular. |

*Rolled steel iron* produced from the same kinds of pig-iron as the above-named, for the production of cast-steel, bore a rupturing strain of from 20·5 to 23·6 tons, and a contraction of area of from 14·2 to 49·6 per cent, and an extension of from 6·1 to 28·3 per cent. Hammered steel iron of the same kind bore a rupturing strain of from 20·8 to 24·5 tons, a contraction of area of from 23·1 to 42·3 per cent, and an extension of from 11·3 to 23·6 per cent.

The following are the results of experiments on the tensile strength of various other kinds of iron and steel of known character made by Mr. Kirkaldy, and which we give here for the sake of comparison :—

| NAMES. | MEAN BREAKING WEIGHT PER SQUARE INCH. Tons. | CONTRACTION OF AREA. Per cent. |
|---|---|---|
| *a. Steel.* | | |
| Turton's cast-steel for tools (forged) | 59·3 | 4·7 |
| Jowitt's double shear steel (forged) | 52·9 | 19·6 |
| Bessemer's patent steel for tools (forged) | 49·8 | 22·3 |
| Wilkinsons's blister steel (forged) | 46·6 | 21·4 |
| Krupp's cast-steel for bolts (rolled) | 41·1 | 34·0 |
| Jowitt's spring steel (forged) | 32·4 | 24·1 |
| Mersey Company's puddled steel (forged) | 31·9 | 35·3 |
| Blockairn puddled steel (forged) | 28·0 | 11·9 |
| *b. Wrought-iron (round and square bars).* | | |
| Yorkshire Low Moor | 27·5 | 49·8 |
| „ Bowling | | |
| „ Farnley | | |
| Lanarkshire ◇ Govan ◇ | 26·0 | 49·4 |
| Lancashire best rivet | 24·0 | 48·6 |
| Staffordshire charcoal (4) | 25·6 | 60·9 |
| „ BB scrap | 26·5 | 52·0 |
| Durham Best Best | 23·9 | 18·3 |
| Ditto | 22·6 | 11·7 |
| South Wales | 18·5 | 9·8 |

When comparing these results with those obtained with Heaton's steel and iron, it will be seen that Heaton's products are somewhat harder, as the contraction of area is generally greatest with the toughest and softest kinds. But, on the whole, the experiments before us are satisfactory if we consider that Heaton's sample bars have been made experimentally only, and are consequently at a disadvantage with those of a regular manufacture, and if we take into consideration that other circumstances may influence the tensile strength of steel (page 16).

Professor Miller has analysed the *steel-iron*, whose tensile strength has been ascertained by Mr. Kirkaldy to be 23 tons per square inch, a statement by no means contradictory to the composition of the iron as shown by the analysis. We much regret that Professor Miller has not also made an analysis of the *hammered cast-steel*, whose tensile strength was found by Mr. Kirkaldy to be 43 tons per square inch.

These bars of cast-steel are thus described in Dr. Mallet's certificate of identification :—

"I certify that certain round rolled bars of Heaton's patent steel-iron, marked and numbered, and also certain bars of *rolled cast-steel* and square bars of *tilted cast-steel*, also marked and numbered, were made on the 10th of July, 1868, at Langley Mills Steel Works, by Mr. Heaton's patent process, in my presence, and in that of Dr. Miller (except in so far as that Dr. Miller, through illness, was unable to wait for *the 'pouring' and tilting, &c., of the cast-steel*), that the whole were made from a mixture of equal weights of Clay Lane No. 4 (Cleveland's) pig-iron, and of Stanton (BBB pig) Northamptonshire iron treated in Heaton's patent converter, and that the above bars of steel-iron and cast-steel were forwarded thence, in cases under my seal, to Mr. Kirkaldy's Testing Works, London. That I there identified the said bars when taken out of the case in my presence, and that certain of those bars were tested before me as to the breaking strain and amount of elongation by Mr. Kirkaldy, and that the results of such testings are those referred to in my 'Preliminary Report.'"

These bars, therefore, most probably belong to the steel which Professor Miller's preliminary report designates as 10 B or 10 C, or the bars were perhaps taken from both kinds; neither of them has been analysed, although this appears to be absolutely required to clear up the doubt still hanging over Heaton's cast-steel, concerning its proportion of phosphorus. In the controversy on the value of Heaton's process, which has been carried on for some time in different periodicals and newspapers, Professor Miller's analysis of the crude steel has been taken as a basis for judging the hammered cast-steel, which undoubtedly has a different composition and less impurities than the original crude steel. We perfectly coincide with the opinion that part of the impurities are contained in the crude steel as intermixed or disseminated slag, and it remains to be proved how far these impurities, especially phosphorus, have been eliminated by the subsequent treatment of crude steel as described by Drs. Miller and Mallet.

The elimination of phosphorus is said to be one of the striking features of Heaton's process, but Professor Miller's analyses would appear to show that, on this special point, Heaton's process has no advantage over the common puddling process.

According to Professor Miller's analyses, the pig-iron employed contained 1·455 per cent of phosphorus, which proportion was reduced in the crude steel to 0·298 per cent, and in the steel-iron to 0·292.

Results with regard to the elimination of phosphorus by the puddling process are given on pages 833 and 842 of our second volume.

In Ure's "Dictionary of Arts and Mines," ii., 726, the following illustrations are quoted:—

| | | |
|---|---|---|
| Pig iron . . . . | 3·030 | per cent of phosphorus |
| Puddled bar . . . | 0·838 | ,, ,, |
| Rough down bar . | 0·572 | ,, ,, |

The finished bar was cold-short in the highest degree.

| | | Phosphorus. Per cent. | Manganese. Per cent. |
|---|---|---|---|
| Pig-iron | containing | 2·60 | 7·20 |
| Puddled bar | ,, | 0·30 | 0·30 |
| Ditto | ,, | 0·20 | |
| Finished bar | ,, | 0·11 | |

The finished bar exhibited none of the cold-short quality; it was exceedingly ductile; indeed, excellent horse-shoes were made from it.

Another question, important to Heaton's process, is to know the exact proportion of phosphorus that wrought-iron and steel may safely contain without being injured in their physical properties; and we are sorry to state that that proportion requires further investigation, although no research can ever lead to the determination of a definite amount, for the following reason:—Iron containing phosphorus, takes, upon cooling, a crystalline texture, and thus becomes brittle or cold-short; but if forged immediately after heating, the crystalline texture and the cold-shortness will be lessened, and the more so the longer the iron is under the hammer.

The influence of proper treatment is confirmed by what Dr. Percy relates of the Low Moor iron. It is not alone the noxious ingredients (phosphorus and sulphur) which the materials may or may not contain, which ensure the production of a superior iron, but, to a certain extent, the care devoted to the different manipulations, a fact plainly proved by the Low Moor iron, produced from iron ores not less contaminated than those of many other iron districts. The following analysis of an experimental armour-plate, manufactured by the Low Moor Company, has been made in Dr. Percy's laboratory by Mr. Tookey (Percy's "Metallurgy," ii., 735:—

| | |
|---|---|
| Carbon | 0·016 |
| Silicon | 0·122 |
| Manganese | 0·280 |
| Nickel | distinct traces |
| Cobalt | „ „ |
| Sulphur | 0·104 |
| Phosphorus | 0·106 |
| Iron (by difference) | 99·372 |

The opinion of different investigators on the influence of phosphorus upon wrought-iron and steel are recorded on pages 30, 110 and 114, and on pages 306 and 691 in vol. ii. We have already shown, by analyses, that the results of Heaton's process with regard to the elimination of foreign matters are similar to those of the puddling process; this most probably is the case, as the wrought-iron in both cases is produced in a pasty state, differing from the Bessemer process, which yields the wrought-iron in a liquid state.

Mr. Kirkaldy's experiments classify the one product of Heaton's process under wrought-iron, and the other under steel, as the former breaks at a burden of 23 tons per square inch, and the latter at 43 tons, which is perfectly comformable with experience.

The following is a detailed statement of the actual cost per ton of making steel and steel-iron, or wrought-iron, by Heaton's patent process, at Langley Mill Steel Works:—

### 1.—*Converting.*

| | £ | s. | d. |
|---|---|---|---|
| Pig, present price | 3 | 0 | 0 |
| Coke | 0 | 1 | 3 |
| Melting and converting, wages | 0 | 2 | 6 |
| Nitrate of soda | 1 | 4 | 0 |
| Waste in pig C. 10 per cent. | 0 | 6 | 0 |
| Expenses on cupola and converter (wear and tear) | 0 | 0 | 6 |
| Labourage, engine, oil, &c. | 0 | 0 | 4 |
| Cost of rough or ball steel | £4 | 14 | 7 |
| Add 10 per cent for management | 0 | 9 | 5 |
| | £5 | 4 | 0 |

### 2.—*Steel from Patent Furnace in Ingots (Estimated Expense).*

| | | | |
|---|---|---|---|
| Rough or ball steel (1) | 4 | 14 | 7 |
| Removing to furnace while hot, including crane | 0 | 0 | 6 |
| Coal (at 6s. per ton) | 0 | 6 | 0 |
| Wages | 0 | 6 | 0 |
| Expense of ingot moulds | 0 | 0 | 6 |
| Wear and tear of furnace | 0 | 1 | 0 |
| Waste | 0 | 5 | 0 |
| Cost of ingots | £5 | 13 | 7 |
| Add 10 per cent for management | 0 | 11 | 5 |
| | £6 | 5 | 0 |

### 3.—*Making into Steel Rails.*

| | | | |
|---|---|---|---|
| Ingot from patent furnace (2) | 5 | 13 | 7 |
| Blooming | 0 | 5 | 0 |
| Coal | 0 | 4 | 6 |
| Removing blooms to furnace | 0 | 0 | 6 |
| Rolling and heating | 0 | 6 | 0 |
| Sawing, straightening, and punching | 0 | 3 | 0 |
| Expenses, to furnacemen | 0 | 1 | 0 |
| Cost of steel rails | £6 | 13 | 7 |
| Add 10 per cent for management | 0 | 13 | 5 |
| | £7 | 7 | 0 |

### 4.—*Making into Cakes.*

| | £ | s. | d. |
|---|---|---|---|
| Rough or ball steel (1) | 4 | 14 | 7 |
| Heating | 0 | 2 | 6 |
| Stamping | 0 | 1 | 0 |
| Coals | 0 | 3 | 0 |
| Breaking and removing | 0 | 2 | 6 |
| Incidental expenses | 0 | 0 | 6 |
| Cost of cakes | £5 | 4 | 1 |
| Add 10 per cent for management | 0 | 10 | 11 |
| | £5 | 15 | 0 |

### 5.—*Melting for Ingots.*

| | | | |
|---|---|---|---|
| Steel cake (4) | 5 | 4 | 1 |
| Melting, including cokes, crucible, and wages | 5 | 10 | 0 |
| Cost of cast-steel ingots | £10 | 14 | 1 |
| Add 10 per cent for management | 1 | 1 | 11 |
| | £11 | 16 | 0 |

### 6.—*Tilting.*

| | | | |
|---|---|---|---|
| Ingots for best cast-steel (5) | 10 | 14 | 1 |
| Coals for furnace | 0 | 5 | 0 |
| Engine men | 0 | 5 | 0 |
| Coals to boiler | 0 | 1 | 6 |
| Cogging-down | 1 | 0 | 0 |
| Finishing | 2 | 0 | 0 |
| Cost of best bar-steel, "tilted" | £14 | 5 | 7 |
| Add 10 per cent for management | 1 | 9 | 5 |
| | £15 | 15 | 0 |

### 7.—*Ingots to Mill.*

| | | | |
|---|---|---|---|
| Ingots (5) | 10 | 14 | 1 |
| Furnace coal | 0 | 5 | 0 |
| Rolling | 0 | 8 | 0 |
| Heating | 0 | 4 | 0 |
| Cogging-down, coals, &c. | 1 | 5 | 0 |
| Engine men, grease, oil, &c. | 0 | 2 | 6 |
| Stock takers | 0 | 2 | 0 |
| Cost of best bar-steel, "rolled" | £13 | 0 | 7 |
| Add 10 per cent for management | 1 | 6 | 0 |
| | £14 | 6 | 7 |

| 8.—*Steel-Iron.* | £ | s. | d. |
|---|---|---|---|
| Rough, or ball steel (1) | 4 | 14 | 7 |
| Balling | 0 | 6 | 0 |
| Blooming | 0 | 1 | 6 |
| Re-heating | 0 | 1 | 6 |
| Extra heating and hammering | 0 | 0 | 9 |
| Mill furnace men | 0 | 2 | 0 |
| Rolling | 0 | 4 | 0 |
| Stock takers | 0 | 2 | 0 |
| Coals | 0 | 4 | 0 |
| Waste | 0 | 2 | 0 |
| Cost of steel-iron | £5 | 18 | 4 |
| Add 10 per cent for management | 0 | 11 | 8 |
|  | £6 | 10 | 0 |

## The Uchatius Steel Process.

M. Uchatius, an Austrian officer, is the inventor of this steel process, which was first brought under public notice at the Paris Exhibition in 1855. By this method, steel is produced direct, by mixing granulated cast-iron with iron ore and brown-stone in crucibles. White radiated pig-iron is usually employed. For the purpose of granulating the pig, about 35 kilos. are fused in plumbago crucibles, which are heated with coke, and the fused metal is poured out through a broom. Rostaing employs centrifugal power for dividing the liquid pig-iron. The granulated pig is then mixed with a certain quantity of iron ore and brown-stone, and more or less wrought-iron is added, according to the degree of softness required for the steel. Hard steel, for example, is produced from a mixture of 1000 parts of pig-iron, 250 of sparry iron ore, and 15 of brown-stone; and soft steel, from a mixture of 1000 of pig-iron, 250 of sparry iron ore, 15 of brown-stone, and 200 of wrought-iron; the mixture is fused in plumbago crucibles 0·4 metre high, and 0·16 metre wide, of a capacity of 14 or 15 kilos. Coke is employed as fuel, and the fusion is effected in an air furnace, in from 1¾ to 2¼ hours. After having removed the slag, the steel is cast into a mould, and the ingots are drawn out under hammers, being re-heated several times.

The resulting steel is chiefly used as tool steel.

When oxide of iron, formed by heating granulated pig-iron in a reverberatory furnace, is employed instead of iron ore, the crucibles are less attacked.

Uchatius's process has been tried experimentally at Sollingerhütte, near Uslar, in Hanover, but a less uniform and inferior steel resulted than from the method of producing cast-steel from blister steel. The steel contained sulphur and silicon, and its production requires more coke and crucibles. Owing to the addition of oxide of iron, the crucible yielded only ¾ of the quantity of steel which is produced in the common cast-steel process, whilst the same time was occupied in melting, and consequently the consumption of coke in both processes stands in the proportion of 4 : 3. The slag attacks the crucibles so much that they can only be used once.

The Uchatius process has been in constant operation for about ten years in Wykmannshyttan in Sweden, and the marked success which has there attended it may be ascribed to the great purity of the ore which is mixed with the iron, belonging as it does to the purest and richest kind of magnetic ore. The steel produced is very tenacious and uniform in grain, and is used exclusively by the Royal Mint in Stockholm for dies of coining presses, polished rolls, &c. It is sold at Gefle mostly in the form of bar steel of small dimensions, at a price of from 30s. to 35s. per cwt.

## The Obuchow Steel Process.

Pure white charcoal pig-iron is re-melted in a cupola furnace, and run into a large clay crucible, previously heated to white heat, and already containing malleable iron and steel scraps, magnetic iron ore, titaniferous black sand and clay, or arsenious acid and magnetic iron ore alone; the crucible is then heated until the contents are perfectly fluid, and the remaining ingredients, namely, arsenious acid and saltpetre, are added, the whole being well stirred.

The steel is cast in vertical cast-iron moulds. The ingots are cooled down to red heat, and tilted under hammers.

Obuchow produces by his method twenty-two different sorts of steel, ranging from the softest kind up to the very hardest tool steel. The steel is principally used in the manufacture of cannons, guns, &c.

The proportion in which the ingredients are mixed, exerts an essential influence on the quality of the steel.

The following are analyses of Obuchow's cannon steel, made by Chodnew :—

| | *a.* | *b.* |
|---|---|---|
| Iron. . . . . . . . | 98·76 | 98·75 |
| Carbon (combined). . | 1·02 | 1·25 |
| Carbon (graphitic). . | 0·15 | |
| Silicon. . . . . . | 0·04 | trace |

## C. Production of Steel by Fusing Pig-Iron together with Wrought-Iron.

### The Siemens-Martin Steel Process in Open Hearths.

An excellent account of this process is given in the following words, in a pamphlet by Mr. C. W. Siemens, "*On the Regenerative Gas Furnace as applied to the Manufacture of Cast-Steel*" :—

" Some method of effecting the fusion of steel more cheaply than in crucibles, as well as in larger masses, has long been a desideratum. Heath, the discoverer of the beneficial action of manganese, was the first (in 1845) to conceive that cast-steel might be produced in large quantities, by fusing wrought- and cast-iron together, upon the open hearth of a reverberatory furnace. The wrought-iron was introduced into another part of the furnace, forming a bank between the bath of fluid metal and the chimney, to be there heated by the waste heat of the flame, previously to its being pushed forward into the liquid, in order to be dissolved. Fearing the effect of the ashes from a common fire-place, Heath proposed to heat his furnace by jets of gas, and there is every probability that his experiments would have been crowned with success, if he had possessed the means of imparting to his flame the intensity of heat and, at the same time, the absence of cutting draught, which are essentially necessary. Since the date of Heath's patent, the fusion of steel in an open furnace has formed the subject of an extensive series of experiments, by Sudre, in France. The experiments of M. Sudre were made at the Montataire Iron Works, at the expense of the Emperor of the French, and were superintended, on his behalf, by three members of the French Institute; MM. Sainte-Claire Deville, Treuille de Beaulieu, Colonel of Artillery, and Caron, Captain of Artillery, who have given an able report on the subject, showing that it is just possible to raise the heat of an ordinary furnace by means of a fan-blast, sufficiently to effect the fusion of tool steel upon the open hearth, in protecting the metal by a layer of glass, but that the rapid destruction of the furnace, the cost of fuel, and other difficulties attending the operation, were such as to render the process, commercially, of doubtful value.

"The regenerative gas furnace is so manifestly suitable for the operation of melting steel, both in pots and on the open hearth, that my attention was directed, from the first, towards this object. The early experiments conducted by my brother and myself at Sheffield failed, however, partly on account of certain irregularities, arising from defects in the furnace which have since been removed, but chiefly in consequence of the want of determination, on the part of the manufacturers and their workmen, to persevere with us to the attainment of the proposed results.

"In 1862, Mr. Charles Attwood took a license to apply the regenerative gas furnace to the melting of steel upon the open hearth, in connection with certain chemical processes or mixtures of his own. I supplied the design of a furnace which answered the purpose, except that the quality of steel produced was not such as Mr. Attwood desired. This circumstance decided him to carry out his process in closed pots, heated in the same furnace.

"In 1863, my friend, M. Le Chatelier, Ingénieur en chef des Mines, elaborated a process for producing steel from cast-iron by puddling and melting the hot puddled blooms in a bath of cast-iron, prepared in a regenerative gas furnace, upon a bed of *bauxite* of the following composition:—

| | | |
|---|---|---|
| Silica. . . . . . . . . | 13 to 17 | per cent |
| Alumina. . . . . . . . | 60 to 65 | „ |
| Peroxide of iron . . . . | 4 to 8 | „ |
| Water in combination . . | 15 to 17 | „ |

This material possesses the advantage of being exceedingly infusible, and of containing no materials that could impart hurtful ingredients to the steel. A furnace of great heating power was constructed by Messrs. Boigue, Rambour, and Co., at their works near Montluçon in France, under my superintendence, and would certainly have accomplished the desired object, if the company had displayed the least determination to succeed. The furnace bottom of bauxite did not succeed, as it was not solidified by the heat, and rose to the surface of the liquid bath,—but this defect was soon rectified by the substitution of a white sand bottom. Through some carelessness, however, the covering arch of the furnace was damaged by excess of heat; and this slight accident, which proved nothing except an ample sufficiency of heating power, sufficed to deter the company from pressing on to the attainment of that success which was so nearly within their reach. In the meantime I had granted a license to Messrs. Emile and Pierre Martin, of the Sireuil Works, to melt steel, both in pots and on the open hearth, and a furnace was erected by them in 1864 which was chiefly intended for a heating furnace, but was, at the same time, constructed of such materials (Dinas brick) and in such a form as to be also applicable for melting steel.

"With this furnace, which was really less suitable than those previously erected, MM. Martin have succeeded in producing cast-steel of a good quality and of various tempers, and their produce was awarded a gold medal at the great French Exhibition in 1867. MM. Martin have since patented various arrangements of their own, such as the employment of particular *fluxes* to cover the surface of the molten metal, the application of a separate furnace for heating the iron before charging it into the melting furnace, and the employment of particular brands of cast- and wrought-iron, which may be useful under special circumstances, but which form no essential part of the general solution of the problem.

"Having been so often disappointed by the indifference of manufacturers and the antagonism of their workmen, I determined, in 1865, to erect experimental or 'sample steel works' of my own at Birmingham, for the purpose of maturing the details of these processes, before inviting manufacturers to adopt them. The first furnace erected at these works is one for melting the higher qualities of steel in closed pots, and contains sixteen pots of the usual capacity. The second, erected in 1867, is an open bath furnace, capable of melting a charge of 24 cwts. of steel every 6 hours. Although these works have been carried on under every disadvantage, inasmuch as I had to educate a set of men capable of managing steel furnaces, the result has been most beneficial, in affording me an opportunity of working out the details of processes for producing cast-steel from scrap iron of ordinary quality, and also directly from the ore, and in proving these results to others."

Messrs. Siemens and Martin have combined their patent rights for the purpose of commercially working their inventions, so far as they relate to the manufacture of steel by the above-named process.

The whole process is conducted in Siemens's regenerative gas furnace, the bed of which is similar in shape to a puddling furnace. The direction of the flame is from end to end, and the regenerators are placed transversely below the bed, which is supported on iron plates kept cool by a current of air. The air enters beneath the bed plates in front, and escapes by two ventilating shafts at the back of the furnace near the ends. This cooling of the bed is very necessary to keep the slag or melted metal from finding its way through into the regenerator chambers. The upper part of the furnace is built entirely of Dinas brick.

The roof of the furnace* can sustain 200 charges without requiring repair, and it can be re-constructed, if desired, without first cooling down the furnace. For this purpose the supply of gas is shut off, and the whole furnace is filled up with pieces of brick and with sand, so that the filling-in material touches the roof all over its surface. The brick roof can be removed, and a new one built in its place upon the solid support formed by the block of sand. When the new roof is arched in completely, and is capable of supporting itself, the sand is withdrawn from the furnace through the doors, and the whole is again ready for working. An operation of this kind has been performed in Sireuil in the course of a few hours.

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* Köhn, Manufacture of Iron and Steel, p. 126.

There are three doors in the front of the furnace, one in the centre immediately over the tap-hole, and two near the bridges, through which the bed can be repaired when necessary, and ingot ends or other heavy scraps be charged in. Sloping shoots are provided at the back of the furnace, through which long bars, such as old rails, may be conveniently charged, and beneath these are openings for charging the pig-iron. The upper end of the shoots is on a level with an elevated charging platform behind the furnace.

The bottom of the furnace is formed of siliceous sand, which answers exceedingly well if properly selected and treated.

Instead of putting moist sand into the cold furnace, as is usually done in preparing the bottoms of furnaces for heating or melting iron or copper, Mr. Siemens dries the sand, and introduces it into the hot furnace in layers of about 1 inch in thickness. The heat of the furnace must be sufficient to fuse the surface of each layer; that is to say, it must rather exceed a welding heat at the end of the operation, in order to impart additional solidity to the uppermost layers. Care must be taken that the surface of the bath assume the form of a shallow basin, being deepest near the tap-hole. Some white sand, such, for instance, as that from Gornal, near Birmingham, will set, under these circumstances, into a hard impervious crust capable of surviving from 20 to 30 charges of liquid steel without requiring material repair. If no natural sand of proper quality is available, white sand, such as that of Fontainebleau, may be mixed intimately with about 25 per cent of common red sand, when the same result will be obtained.

The actual requirement is sand containing about 90 per cent of silica and 10 per cent of alumina or magnesia.

In tapping the furnace, the loose sand near the tapping-hole is removed, when the lower surface of the hard crust will be reached. The lowest point of this surface is then pierced by means of a pointed bar, upon the withdrawal of which the fluid metal runs out from the hottest and deepest portion of the bath into the ladle in front of the furnace.

M. Le Chatelier proposes to mix the natural bauxite, of which the bottom of the experimental furnace at the works of MM. Boignes, Rambourg and Co., near Montluçon was first made, with about 1 per cent of chloride of calcium in solution, in order to calcine the mixture, and to form it into moulded masses of highly refractory material.

A hard bottom being thus prepared, and the heat of the furnace raised to whiteness, it is ready to receive the materials to be melted.

If these materials consist of bar iron, or of old iron and steel rails, they are cut into lengths of about 6 feet, and are introduced into the furnace through slanting hoppers from the elevated platform at the back, so that their ends rest upon the sand bottom forming the bath.

If the capacity of the furnace is such that charges of 3 tons can be formed, about 6 cwts. of grey pig-iron are introduced through the ports or short hoppers below the main charging hoppers before mentioned. As soon as a bath of pig metal is formed, the heated ends of the rails or bars begin to dissolve, causing the bars to descend gradually. By partially closing the mouths of the charging hoppers, a regulated quantity of flame is allowed to escape from the furnace, in order to heat the descending bars of metal previous to their entry into the melting chamber, the object being to maintain the high temperature of the furnace, notwithstanding the constant introduction of cold metal. The escape of the products of combustion which are thus withdrawn from the regenerators is, in reality, a means of increasing the heat of the furnace, because, having been in contact with comparatively cold metal, they would be at a heat inferior to that of the upper portions of the regenerators, and would, therefore, only lower their temperatures.

M. Martin considers that the charging of cold materials sensibly affects the temperature of the furnace itself, and interferes with the regularity of the operation. He therefore employs, besides the regenerative gas furnace, two accessory furnaces, one for melting the pig-iron, and the other for heating the iron scrap up to a white heat before its introduction into the Siemens furnace.

As the bars from their gravity sink in the hoppers, they are followed up by others, until the metal charged amounts to about 3 tons, all of which will be rendered fluid within about 4 hours from the time of commencing the charge. The metallic bath is tested, from time to time, by the introduction of a bar through one of the front doors of the furnace, and if the bath should become thick before the end of the operation, although the heat may have been maintained, it will be necessary to introduce an additional quantity of pig-iron. All the metal being liquid, a sample is taken out by means of a small iron ladle, and plunged into cold water while still red-hot. On breaking this sample upon an anvil, the temper and quality of the metal may be fairly judged of. Its fracture should be bright and crystalline, betokening a very small proportion of carbon (not exceeding 0·1 per cent) and the metal should be tough and malleable, notwithstanding its sudden cooling. From 5 to 8 per cent of spiegeleisen (containing not less than 9 per cent of manganese) is thereupon charged through the side openings upon the bank of the furnace, and allowed to melt down into the bath, which is then stirred and made ready for tapping in the manner before described.

The amount of carbon introduced with the spiegeleisen, determines the temper of the steel produced, the manganese being necessary to prevent red-shortness, unless Swedish or Styrian iron is used.

When old iron rails or scraps of inferior quality are charged, the addition of manganese does not suffice to effect the necessary purification of the steel produced; but the perfectly liquid condition of the bath, together with the unlimited time available for chemical reaction, offer extraordinary facilities for the introduction of such materials as may be found to combine with sulphur, phosphorus, silicon, or arsenic, which are the usual impurities to be dealt with.

Mr. Siemens has instituted experiments in this direction, and has obtained beneficial results from the introduction of litharge into the bath, in conjunction with oxidising salts containing strong bases, such as alkaline nitrates, chromates, chlorates, stannates, titanates, &c.

The choice of the reagents, and the quantity to be employed, depend, naturally, on the quality and quantity of objectionable matter to be removed.

By the aid of the process just described, it is possible to convert old iron rails into steel rails of sufficiently good quality, at a cost scarcely exceeding that of re-rolling them into fresh iron rails. The non-expensive nature of the process may be judged of by the fact that extremely little labour is required to conduct it, that the loss of metal does not exceed from 5 to 6 per cent, and that from 10 to 12 cwts. of coal suffice to produce a ton of cast steel.

At M. Verdie's works,* at Firminy in France, there are two Siemens furnaces in constant operation. Each furnace is capable of producing in 12 hours 3500 kilos. (about 3½ tons) of steel ingots at a charge. The pig and scrap-iron employed are previously heated in separate furnaces; the quantity of pig-iron next charged is 900 kilos. The fusion being effected, and the flame of the furnace adjusted to a neutral character, a charge of 200 kilos. of iron and steel scrap, previously raised to a white heat, is introduced into the furnace. This scrap-iron will melt down and combine with the liquid mass of the bath in about 30 minutes. At intervals of ½ an hour, fresh charges of 200 kilos. each, are successively added, and the entire operation occupies about 8 hours; about 2 hours more are, however, required after each charge for fettling the furnace. During the sixth and seventh hour of actual working, after the addition of about 2400 kilos. of wrought-iron and steel scrap to the charge of

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* KÖHN, Manufacture of Iron and Steel, p. 127.

900 kilos. of pig-iron, the mass is converted into a pasty state, approaching wrought-iron in its character, but actually neither steel nor wholly decarburised iron. This mass is then re-carburised by successive additions of 200 kilos. of pig-iron at a time, till a total quantity of 800 kilos. is reached. The pig-iron finally added in this manner is of the same kind as that originally employed; it contains some manganese, and the quantity to be added to each charge is adjusted according to the quality and degree of hardness required.

The metal bath is protected by a slag, composed of charcoal blast-furnace cinders mixed with pure siliceous sand; the time of fusion may therefore be protracted at will.

The loss of metal in this process, at the Sireuil Works, amounted to 7·8 per cent, and the prime cost of ingots to £6 18s. 7d. per ton.

A 3-ton furnace, with gas producer and regenerators, and all the apparatus for moving the ingot moulds, may be estimated at about £500; the first outlay for plant is, therefore, very moderate.

The great importance of this comparatively new process has caused its rapid introduction into many steel works in France, America, Austria, and also in this country, where Mr. Samuelson, M.P., has obtained a license, and commenced operations on a large scale at Banbury, with very satisfactory results.

## The Obersteiner Steel Process.

By this method, pig-iron is melted, together with wrought-iron, in crucibles, and the resulting steel is cast into moulds. This process is still in use in Gefle in Sweden.

The pig- and wrought-iron are mixed in various proportions; in some places, for instance, seven parts of best spiegeleisen, rich in carbon, are melted with seventeen parts of wrought-iron.

At Hirschwang, near Reichenau, the charge for each crucible consists of 29½ lbs. of wrought-iron scrap, 5½ lbs. of radiated white pig-iron, and 1-16th ounce of brown-stone. The resulting steel is tool-steel, No. 6.

When pig- and wrought-iron are of constant composition, the amount of carbon in the mixture may be calculated previously, and steel of any desired hardness produced. Stengel made successful experiments on this point; for the production of soft steel, he employed a mixture of 25 lbs. of Swedish wrought-iron, containing 0·25 per cent of carbon, and 2 lbs. of spiegeleisen containing 5·6 per cent of carbon; the mixture for hard steel consisted of 24 or 25 lbs. and 8 lbs. respectively.

### 2. Production of Steel from Wrought-Iron by Cementation.

In this process, the raw materials, chiefly wrought-iron and fuel, are of essential importance. The resulting steel is principally used for the production of tool steel (page 6), and it has been compared with raw and puddled steels on pages 41 and 65.

Whilst steel works are generally established in the neighbourhood of the ore mines, the manufacture of cement steel is seldom executed in places where the suitable wrought-iron is produced, but rather in localities where good and cheap fuel is to be obtained. Thus, in England, cement steel is mostly manufactured from Swedish wrought-iron, employing mineral coal, chiefly in Sheffield and its neighbourhood, where about 4-5ths of the English steel is produced. Sweden, likewise, exports annually from 40,000 to 50,000 cwts. of cement steel, produced by means of wood fuel.

Jackson's steel works at Rive de Giers, in the department of the Loire in France, produce annually from 110,000 to 120,000 cwts. of cement steel from foreign wrought-iron.

The products of some iron works on the Ural and in the Pyrenees are equal in quality to the Swedish wrought-iron; and cement steel is also produced from the wrought-iron of Siegen in Westphalia, as well as from that of Styria.

The manufacture of cement steel is so old that the date of its first introduction cannot be ascertained. It has been carried on for more than 100 years in England, for about half a century in Sweden, and about 30 years in France and

Germany (Westphalia); it was only introduced into Austria by Tunner in 1852.

The chemical reactions of the process were first explained in 1786 by Monge and Berthollet, but important hints with regard to this manufacture had already been given in 1722 by Réaumur, in his treatise "*L'art de Convertir le Fer Forgé en Acier.*" In later times no essential progress has been made in the process.

Different views are entertained with regard to the formation of cement steel, but it is most probable that the carbonisation of the iron bars, when heated in powdered coal with the exclusion of air, takes place by means of the cyanogen compounds which are formed in the state of gas, rather than by a direct reaction of carbon or carbonic oxide gas (pages 23 and 24). This view is confirmed by the circumstance that hard charcoal, rich in alkalies, yields the best cementation powder, and that its effect becomes exhausted with the disappearance of the alkalies.

In order to form steel, the glowing heat employed must be as high as the melting point of copper (1170° C.), although the carbonisation actually commences at 1000° C. When a higher temperature (1400° C., for instance) is employed, cast-iron will be formed instead of steel. The production of the soft kinds of steel requires a lower temperature than hard steel, and also a different length of time. When one and the same piece of iron of large section, immersed in coal, is repeatedly heated, the carbonisation of the iron will take place only to a certain depth, corresponding to that of the heating operations which had been most effectual; from this it may be concluded that the carbonisation or cementation always commences afresh from the outside of the iron bar, if the chemical process is interrupted by an accidental lowering of the temperature.

In cementing, the fine-grained or fibrous texture of the wrought-iron is transformed into a scaly crystalline texture, owing to an absorption of carbon; the strength and specific gravity becomes lowered, the white colour is turned into grey, the bars show a rough surface and blunted edges, and, according to the degree of cementation, more or less blisters form on the external surface, whence the term blister steel is derived. The blisters are caused either by nitrogen which has been evolved from the cyanogen, or by the formation of carbonic oxide gas, produced by the reaction of the air included in the cement powder, or of the slag contained in the wrought-iron, which may react upon the carbon contained in the softened surface of the bar-iron. When bar-iron of good quality is employed, the blisters will be found less than 1 centimetre in diameter, and uniformly distributed over the whole surface. As these blisters are bright inside, they do not impede the perfect welding, and the cement steel, on being forged, becomes more compact than the iron from which it was produced; while, at the same time, the operation of forging causes the cracks which may be observed on the cross fracture of the bar, and which usually run parallel to the large planes of the bar, to disappear. The absorption of carbon by the bars is not uniform, as they are richer in carbon outside than in the centre. The bars to be cemented must not, therefore, be of too large dimensions, and the blister steel must be subsequently refined either by welding and forging, or by being re-melted. The carbonisation of an iron bar does not usually extend below 18 lines.

As it is impossible to obtain a perfectly uniform temperature in the conversion pots, soft and hard kinds of steel result at the same time, rendering it necessary to sort the steel according to the appearance of the fracture (page 41).

A great deal of Swedish and Styrian cement steel, after being heated to a yellow heat in common forges, or hollow fires, or reverberatory furnaces, is drawn out under hammers or rolls without a previous refining, and is used for the manufacture of springs, files, and other common articles. When a better quality is required, the steel must be previously refined.

## The Materials for the Manufacture of Cement Steel.

1. **Wrought-Iron.**—A superior kind of wrought-iron is required for the production of the best quality of steel. Such steel combines the properties of great hardness and elasticity,

with an easy weldability, and possesses the capability of being polished and of retaining its steely nature for a long time, whilst being treated at higher temperature. The wrought-iron must be as free as possible from all foreign admixtures, and be dense and uniform whether hard or soft. A want of continuity in the wrought-iron makes itself apparent in the cemented bars, which then show larger and smaller blisters in irregular distribution, and likewise irregular clefts and cracks. The latter apparently disappear on forging, but on the finishing operations being performed (the polishing, for instance) they appear again as grey or black spots.

The Swedish wrought-iron produced in the Lancashire finery forge (vol. ii., page 763) is in great repute for the manufacture of cement steel. It is also chiefly used in England; Russian and Styrian wrought-iron likewise gives good results.

Hammered iron is generally preferred to rolled iron, although the latter has a more equal grain, in consequence of its being more uniformly treated. As it is less dense, rolled iron is more easily cemented than hammered iron. Swedish rolled wrought-iron has lately been more generally employed. The steel produced from it does not, however, command such a high price as that produced from hammered iron.

For the production of the best kinds of steel, finery iron is also preferred to puddled iron, which, according to Tunner,* attains a more uniform cementation, as far as can be judged of by the exterior; but the fractures of such bars frequently show flaws in the form of dark stripes, which become more perceptible if the bars are drawn out into fine dimensions, and which cannot be perfectly removed by a further refining.

Steel produced from finery iron is more elastic, and retains its hardness better than that which results from puddling iron. However, puddled iron produced from superior pig-iron, with an addition of Schafhäutl's powder, and which has been rendered as dense as possible by careful welding and hammering, is now applied in England† as well as in

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* Leob., Jahrb., 1857, vi., 91.

† Ibid., 1852, vi., 139.

Austria* to purposes for which formerly Swedish and Russian iron only were used.

**2. Puddled Steel.**†—Railway wheels and rails made of puddled steel were cemented in Newcastle in 1837, as they have been lately also in France, in order to render them very hard and uniform. The cementation of puddled steel takes place more quickly and deeply (above 2 inches deep) than that of wrought-iron.

**3. Cementing Powder.**—The largest and best steel works in England, Sweden, Styria, &c., employ as cementing powder nothing but charcoal, partly in the form of powder, and partly in small pieces not larger than about one-tenth cubic inch. In Sweden, birch charcoal is usually employed; in England, oak charcoal; in Westphalia, beech charcoal; and in Styria, pine charcoal. The compact charcoals made of wood which is rich in alkalies are best adapted, as they facilitate the formation of cyanogen, and exclude the air better, owing to their lying in so compact a state.

Powder which has been used possesses less cementing power, and can only be applied again on being mixed with half or three quarters of fresh powder. It is usually employed on the top and at the bottom to lessen the expense. Fresh powder used alone requires longer time and lower temperature in the cementing operation; heated coals are also less effective than fresh ones. Coke powder cannot be used on account of the amount of ash and sulphur it contains. 1 cwt. of iron charged for cementing requires about ⅛ cubic foot of charcoal.

A great variety of artificial compositions of cementing powder are recommended, but they are not more effective than pure charcoal. Tunner's experiments‡ have proved that an addition of ½ per cent of potash and common salt, on the weight of the charcoal, facilitates the formation of cyanogen, thus accelerating the cementation, and is chiefly effective in the production of the harder kinds of steel rich in carbon. A similar effect is produced by moistening the cementing powder with a dilute solution of wood-ash. Dodd* shortened the time of cementing from three or five days to 75 hours, by employing powdered charcoal with an admixture of 6 per cent of lime and 2 per cent of soda.

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* Leob., Jahrb., 1857, vi., 90.

† Ibid., 1863, xii., 65.

‡ Ibid., 1853, iii., 306; 1863, xii., 65.

An addition of carbonate of baryta† has a still better action than alkalies (page 24).

An addition of animal substances (leather, horn, &c.,) or ferrocyanide of potassium,‡ likewise facilitates the formation of cyanogen.

The cementing powder is either employed in a dry state, or it is previously moistened to prevent it from dusting.

It has been before observed, that illuminating gas free from sulphuretted hydrogen gas has been used for the purpose of cementation (page 23).

4. **Fuel for Heating the Furnaces.**—The nature of the fuel exercises an essential influence upon the cost and duration of the cementation process, and also regulates the construction of the furnaces.

In most steel works, in England and Westphalia, for instance, a long flaming mineral coal, rich in gas, and not too strongly caking, is used. In Sweden, Reichenau, &c., air- and kiln-dried wood is employed; in Styria brown coal is burnt on step grates, and sometimes turf also.

The production of 100 lbs. of cement steel consumes from 75 to 90 lbs. of mineral coal, from 160 to 210 lbs. of brown coal (at Leoben, for instance, 200 lbs. in furnaces having two conversion pots, and 400 lbs. in furnaces with only one such pot), from 200 to 300 lbs. of turf, and from 300 to 325 lbs. of pine wood in pieces, according to their dryness.

At Friedrichsthal|| in Wurtemburg, the waste gases of iron blast furnaces are employed for heating the cementation furnaces, and at Eibiswald,§ the process is conducted with the waste gases of puddling furnaces.

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* B. u. h. Ztg., 1859, p. 144.

† HARTM., Fortschr., v. 244; vi., 247. Polyt. Centr., 1862, No. 6.

‡ DINGL., Bd. 158, p. 205.

|| B. u. h. Ztg., 1858, p. 119.

§ Oesterr. Ingen. Verein, Abtheilung für Berg und Hüttenwesen, Sitzung vom 5, Februar, 1862.

## Cementation Furnaces.

One of these furnaces is represented in Figs. 31, 32, and 33.* It is rectangular, and covered in by a semicircular arch, in the centre of which a circular hole is left 12 inches in diameter; this is opened when the furnace is cooling. It contains two receptacles called "pots," c, c, made either of sandstone or fire-bricks; each pot is 3 feet wide, 3 feet deep, and 12 feet long. One is placed on one side, and the other on the contrary side of the fire-grate, A, B, which occupies the whole length of the furnace, and is 13 or 14 feet long; the grate is 15 or 16 inches broad, and the bars rest from

FIG. 31.

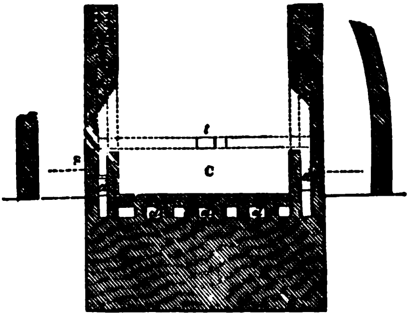
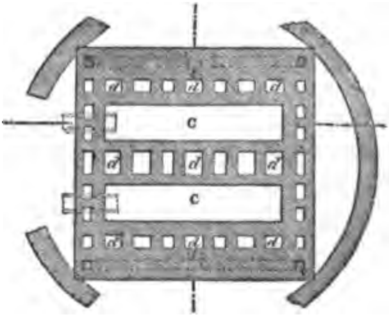


FIG. 32.



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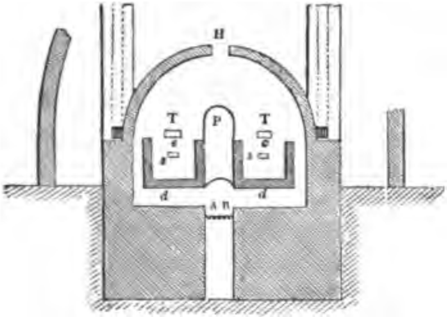
* URE's Dictionary of Arts and Mines, vol. iii., p. 761.

10 to 12 inches below the inferior plane or bottom level of the pots. The height of the arch at the centre is 5½ feet above the top of the pots, the bottoms of which are nearly level with the ground, so that the bars of iron do not require to be lifted so high on being charged into the furnace.

FIG. 33.



The flame rises between the two pots; it also passes below and around them through the horizontal and vertical flues, *d*, and issues from the furnace through the six small chimneys, into a large conical space which is built round the whole furnace, from 30 to 40 feet high, open at the top. This cone increases the draught of the furnace, and carries away the smoke. There are three openings in the front of the arch; two, T, in Fig. 33 above the pots, serve to admit and remove the bars; they are about 8 inches square. A piece of iron is placed in each, upon which the bars slide in and out of the furnace. The workman enters by the middle opening, P, to arrange the bars, which he lays flat in the pots, and spreads a layer of charcoal ground small between each layer. The bars are placed near each other, except those next to the side of the pots, which are placed an inch from it. The last stratum of iron is covered with a thick layer of charcoal, and the whole is carefully overspread with a coat of loam 4 or 5 inches thick.

Furnaces intended for the production of smaller quantities of steel of a certain quality are now and then constructed with one pot only; they consume more fuel than those with two pots.

Furnaces with three pots were formerly used in Sweden; they economised fuel, but did not yield an uniform product, and exerted too strong a pressure upon the supports.

The interior side walls of the furnaces are lined with fire-bricks 5 or 6 inches thick, and the rough walling of 1 foot in thickness is sometimes separated from the lining by a filling-in 4 or 5 inches thick. The arched roof is from 12 to 16 inches thick, and the flatter its construction the less fuel will be consumed; but, on the other hand, the flatness will render the conduct of the manipulation more troublesome. For this reason the small furnaces at Leoben and Hirschwang, near Reichenau, with one pot, are constructed with flat roofs composed of different parts, which may be easily removed by means of a crane, and which allow of an easy manipulation, and enable the time of cooling to be shortened.

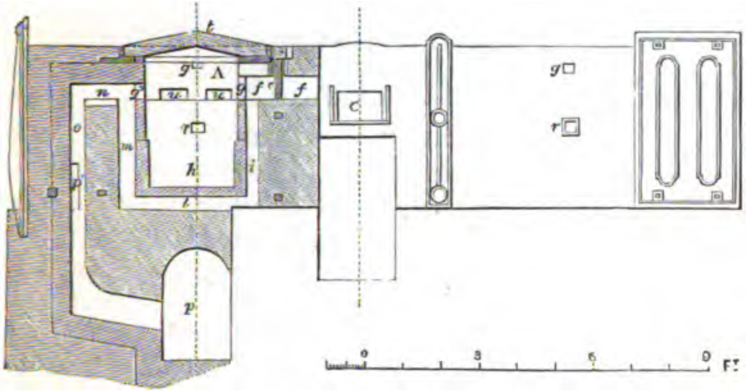
The pots sometimes vary in size with the length of the iron bars; they are from 8 to 15 feet long, from 26 to 36 inches broad, and from 28 to 36 inches high. The smaller pots require more fuel, and the larger ones do not attain an uniform temperature, as their large size makes it difficult to exclude the atmospheric air. Furnaces with two pots usually contain 120, 175, or 240 cwts. of wrought-iron in each pot, according to their dimensions.

The pots of Mayr's Steel Works at Leoben are 10 feet long, 3 feet 3 inches broad, and 3 feet 5 inches high. They have a capacity of 150 or 160 cwts. of wrought-iron with the necessary quantity of cementing powder; they are built of slabs made of the material for fire-bricks. The pots of Fridau's Works at Leoben, in furnaces having one pot only, are 7 feet long, 2½ feet broad, and 3 feet deep; they have a capacity of 60 cwts.

When plane grates are employed, the fire-place is as long as the pots. Step grates are also used in some cases, one on each of the frontal sides of the furnace. Mayr's steel works at Leoben, for instance, has furnaces each with two step grates, the steps being from 12 to 18 inches broad, and the combustion gases are conducted through six flues provided with sliding valves into the arched roof. The furnaces at the most work twenty charges annually.

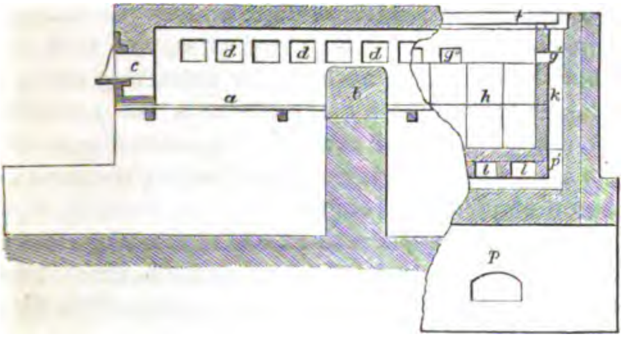
A one-pot furnace with movable roof, constructed by Rittinger, for wood firing, and used in Hirschwang, near Reichenau, is represented in Figs. 34, 35, and 36.

FIG. 34.



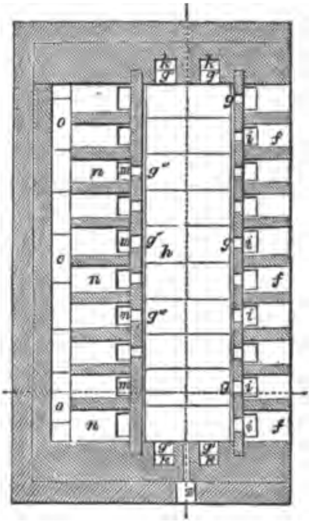
The grate, *a*, is divided into two compartments by the wall, *b*. The flame enters by the openings, *d*, into the channels, *f*, which are provided with the slide door, *e*, whence it partly enters the space, A, above the pot, *h*, through the openings, *g*, and partly rises in the side flues, *i*, on the long side, and descends in the frontal sides in the flues, *k*, through *g'*; the flame then passes through the bottom flues, *l*, into the side flues, *m*, and hence into the horizontal

FIG. 35.



channels, *n*, together with the gases from the space, A, through *g''*. The flame is then conducted into the smoke-collecting channel, *p*, through the descending channel, *o*; the combustion gases from the frontal flues, *k*, enter into *o*, through *p'*. Below each pot, or if possible on the side of it, in order to have room for a solid support, a channel, *p*, is constructed, and two of these unite outside the furnace in a common chimney 54 feet high and 38 square inches wide; *q* is a loop-hole; *r* is an opening for extracting sample bars from the furnace; *s* is a man-hole; *t* is the movable roof formed of fire-bricks and covered with burnt clay and sand; *u* are openings for charging and discharging the furnace.

FIG. 36.



When the application of gas-firing* is intended, it is only necessary to put the gas tube on one of the long sides of the furnace, and to introduce the gas through three openings into the vertical flues on one of the long sides of the furnace; the combustion air is to be introduced through openings above those of the gas tube, and which can be regulated by sliding valves. The flame then rises in the above-named flues, passes above the pot, and descends through the flues on the other long side and those of the frontal sides, into a channel below the pot, which channel communicates with a chimney 30 feet high.

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* B. u. h. Ztg., 1858, p. 119, tabula iii.

Dodd[*] has constructed a furnace for continuous operations.

## Method of Conducting the Cementation Process.

Before the pots are charged, a layer of clay, powdered bricks, or fine quartz sand, 1 or 1½ inches thick, is uniformly spread out upon their bottom, in order to cover cracks which may have been formed; open joints in the other parts of the pots are closed with mortar. Upon that layer of sand, &c., a stratum of cementing powder 1½ or 2 inches high is uniformly spread for receiving the first layer of wrought-iron; this powder is frequently previously wetted with pure water or with loam water. The ordinary sizes of bars employed are from 2 to 5 inches in breadth, and from ⅓ to ¾ of an inch in thickness, a flat form being preferred to those of round or square section. The bars are placed in the pots on their flat side. Thin bars are much sooner converted than thick ones. Réaumur, in his experiments, states that if a bar of iron 3-16ths of an inch thick is converted in 6 hours, a bar 7-16ths of an inch would require 36 hours to attain the same degree of hardness; but, on the other hand, the pots will contain a smaller quantity of iron if filled up with thin bars. The pots may contain 36 per cent of their volume of iron. In filling them, an allowance is made for the expansion of iron by heat, a space of about 2 inches longitudinally and a little less transversely being left between the edges of each layer of bars and the walls, and in like manner the butt ends of adjacent bars in each line must not be brought in contact with one another; a small space is also left between the single bars. The interstices are filled up with cementing powder.

The pot is then filled up to about 4 or 6 inches below the edge, with alternate layers of wrought-iron and cementing powder; the layers of powder are ¼ or ½ an inch thick. At the place where the pot has an opening for drawing samples, one or two shorter bars are placed projecting somewhat beyond the opening, so that they may be easily taken out. Upon the uppermost layer of iron, a layer of cementing powder 2 inches thick is spread out. In order to exclude air as effectually as possible, the whole is then covered with bricks, quartz sand, and clay, which is firmly beaten down. In England, grinder's waste is employed for such covering; this kind of sand contains particles of steel which are superficially oxidised, and frits at a higher temperature to a glaze, forming a covering impervious to the air.

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[*] B. u. h. Ztg., 1859, pp. 144.

At Friedrichstahl, where gas is used for firing, it is considered necessary to cover the uppermost layer of cementing powder first with a layer of loam 1 inch thick, then with a corresponding layer of fine quartz sand, and upon these to place a layer of broken brick, the interstices of which are filled up with loam, and to cover the whole with a thick layer of sand.

The filling of a furnace occupies about 2 days; the flues are then cleaned, the charging openings and the man-hole walled up, and the latter provided with a loop-hole.

The furnace is then gradually brought to the temperature of the melting point of copper (page 211); with a new furnace this is effected in two days, and with an old one in about 24 hours. This temperature is kept as uniform as possible by judiciously stirring the fire about once every hour, by cleaning the grate twice in a day, and also by a suitable distribution of the flame by means of the sliding doors. Towards the end of the operation, the heat is somewhat increased.

An operation occupies from 5 to 9 days, and sometimes even longer, according to the section of the iron bars and the degree of carbonisation intended. After about 170 or 180 hours, the first sample bar is taken out, and its examination in a raw and hardened state (page 211) enables the state of the process to be judged of; 12 or 14 hours later the second sample bar is taken out; when an unaltered kernel of soft iron is no longer apparent in the centre, the conversion is considered to be complete. The fire is now allowed to go out, and the furnace is left to cool for 3 days; the man-hole stoppings are then removed, and on the sixth day the withdrawal of the cemented bars is commenced; this takes one or two days more, so that the whole operation occupies from 17 to 20 days. From fifteen to twenty operations are made annually.

The average increase of weight in the conversion of bar iron into cement steel, is from ½ to ¾ per cent.

### Examples of the Manufacture of Cement Steel.

1. **Furnaces Heated with Mineral Coal.**—In Yorkshire,* furnaces with two pots are used. One furnace is charged with from 16 to 18 tons of bar iron, and steel for melting purposes requires from 9 to 10 days, for shearing 8 days, and for spring temper 7 days. 100 lbs. of cement steel are produced at a consumption of about 75 lbs. of coal. The thickness of the iron bars employed is generally ¾ of an inch, and their breadth about 3 inches.

2. **Furnaces Heated with Brown Coal.**—At Mayr's Steel Works in Leoben, furnaces with two pots are in use, and one pot is capable of containing from 150 to 160 cwts. of iron, which form from eighteen to twenty-five layers, according to the thickness of the bars. The bars employed are either 2½ inches broad and 1¼ inches thick, or 1½ inches square. An operation is completed in 200 hours, and a similar time is allowed for cooling the furnace, which is then discharged in 2 days. The bar iron, in its conversion into steel, increases in weight by ½ or ¾ per cent. One operation consumes about 135 cubic feet of small charcoal as cementing powder, and 200 lbs. of small brown coal per 100 lbs. of steel are consumed. The furnace is charged and discharged by four men, and is attended by one man during the operation; fifteen operations are made in one year.

The furnaces at Fridau's Steel Works in Leoben are provided with one pot only, which has a capacity of 60 cwts. The time occupied in charging the furnace is two days, and that for conversion from six to eight days. The furnace is allowed three days for cooling, and is discharged in two days. Five cubic feet of cementing powder per charge, and 4 cwts. of small brown coal per cwt. of steel are consumed; the increase of weight in the steel amounts to 1 per cent.

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* Dingl., Bd. 91, p. 460.

3. **Furnaces Heated with Wood.**—The furnaces in Sweden* with two pots have a capacity of from 250 to 350 cwts. of iron, and an operation is completed in from 9 to 12 days, at a consumption of 20 cubic feet of wood, in pieces 36 inches long, and at an expense of about 1s. 9½d. per cwt. of steel. The cement steel is drawn out into bars ⅜ of an inch square, losing 6 per cent in weight (including the increase on cementing), at an expense of about 2s. 8d. The cost per cwt. of drawn-out steel amounts, therefore, to about 4s. 8d., and to from 13s. 6d. to 18s. 8d. if the price of the iron is included.

At Hirschwang, near Reichenau,† furnaces with one pot and movable roof are in use. One charge of 140 cwts. 48 lbs. of wrought-iron in bars 5-4th inches square, yields 140 cwts. 69 lbs. of hard cement steel at a consumption of 3996 cubic feet of wood which is not perfectly air-dried. An operation occupies 15¼ days, two of which are used for charging, and four for cooling and discharging the furnace. Air is admitted into the furnace through the sliding valves, roof, &c., 24 hours after the conversion is completed.

The furnaces at Friedrichsthal‡ likewise have only one pot, and are heated with the waste gases from iron blast furnaces.

From 50 to 60 cwts. of bar-iron are charged and converted into cement steel in from eight to ten days, or in 15½ to 17½ days when the time for charging and discharging is included. The increase of weight in the steel amounts to 0·6 or 0·8 per cent. The expense for cementing 1 cwt. of iron only amounts to about 3d.

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* TUNNER, das Eisenhüttenwesen Schwedens, 1858, p. 84.

† RITTINGER'S Erfahrungen, 1861, p. 36.

‡ B. u. h. Ztg., 1858, p. 119.

## PRODUCTION OF DAMASKED STEEL BY FUSING WROUGHT-IRON WITH COAL.

The damasked steel is characterised by its behaviour when a polished surface is etched with acids, when owing to the different degree of solubility of the compounds which are richer or poorer in carbon a design of dark and light lines in a certain order will appear. The term damask is derived from the city of Damascus, where Indian steel has been produced for centuries past. Those parts of the steel which are easily attacked attain a grey colour as graphite becomes exposed, while those parts which are less easily attacked form lighter lines in relief. The damasked steel varies in its designs, some having parallel lines, and others lines of a screw-like form, or they resemble mosaic.*

Schafhäutl suggests that the least soluble compound of the steel is silico-carbide of iron. On being re-melted, or suddenly cooled, damasked steel loses its designs more or less.

As uniformity is the principal characteristic of good steel, the high degree of hardness and elasticity which the various kinds of damasked steel possess, can be obtained only by very pure raw materials, which must be subjected to extremely careful treatment. The superior qualities of damasked steel are also attributed to the presence of a certain amount of tungsten, nickel, manganese, &c., and analyses have determined these substances in the steel.

**Production of Indian Steel or Wootz**† **(Natural Damask).**—The wootz ore consists of magnetic oxide of iron united with silica in proportions which appear to differ but little, being generally about 42 of silica and 58 of magnetic oxide. Its grains are of various sizes down to a sandy texture. The natives prepare it for smelting by pounding the ore and winnowing away the stony matrix, a task at which the Hindoo females are very dexterous. The manner in which the iron ore is smelted and converted into wootz or Indian steel by the natives of the present day is probably the same that was practised by them at the time of the invasion of Alexander, and the process is uniform from the Himalaya Mountains to Cape Comorin. The furnace or bloomery in which the ore is smelted is from 4 to 5 feet high. It is somewhat pear-shaped, being about 2 feet wide at the bottom and 1 foot at the top. It is built entirely of clay, so that a couple of men can erect it in a few hours, and have it ready for use the next day. There is an opening in front about a foot or more in height, which is built up with clay at the commencement, and is broken down at the end of each smelting operation. The bellows are usually made of a goat's skin, which has been stripped from the animal without ripping open the part covering the belly. The apertures of the legs are tied up, and a nozzle of bamboo is fastened in the opening formed by the neck. The orifice of the tail is enlarged and distended by two slips of bamboo. These are grasped in the hand and kept close together in making the stroke for the blast; in the returning stroke they are separated to admit the air. By working bellows of this kind with each hand alternately, a pretty uniform blast is produced. The bamboo nozzles of the bellows are inserted into tubes of clay, which pass into the furnace at the lower corners of the temporary wall in front. The furnace is filled with charcoal, and a lighted coal being placed before the nozzles, the mass in the interior is soon kindled. As soon as this is accomplished, a small portion of the ore, previously moistened with water to prevent it from running through the charcoal, but without any flux whatever, is laid on the top of the coals, and covered with charcoal to fill up the furnace.

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* Bgwkfd., v., 391.

† URE's Dictionary of Arts and Mines, vol. iii., p. 764.

In this manner ore and fuel are supplied, and the bellows are worked for three or four hours, when the process is stopped; the temporary wall in front being broken down, the bloom of more or less carbonised iron, about 40 lbs. in weight, is removed by a pair of tongs from the bottom of the furnace. It is then beaten with a wooden mallet to separate from it as much of the scoria as possible, and while still red-hot, it is cut through the middle, but not separated, the incision being merely to show the quality of the interior of the mass.

In this state it is sold to the blacksmith, who makes it into bar-iron. The proportion of such iron made by the natives from 100 parts of ore is about 15 parts, or about 12 per cent of very pure wrought-iron.

In converting the wrought-iron into steel, the natives cut it into small pieces to enable it to pack better in the crucible, which is formed of refractory clay mixed with a large quantity of charred husk of rice. It is seldom charged with more than a pound of iron, which is introduced with a proper weight of dried wood chopped small, and both are covered with one or two green leaves, the proportions being, in general, 10 parts of iron to one of wood and leaves. The mouth of the crucible is then stopped with a handful of tempered clay, rammed in very closely to exclude the air. The wood preferred is the *Cassia auriculata*, and the leaf that of the *Asclepias gigantea*, or the *Convolvulus laurifolius*. According to Fremy,* these plants are rich in nitrogen and phosphorus, which substances are said to facilitate the formation of steel (page 23). As soon as the clay plugs of the crucible are dry, from twenty to twenty-four of them are built up in the form of an arch in a small blast furnace. They are kept covered with charcoal, and subjected to heat urged by a blast for about 2½ hours, when the process is considered to be complete. The crucibles are now taken out of the furnace and allowed to cool; they are then broken, and the steel is found in the form of a cake rounded by the bottom of the crucible. When the fusion has been perfect, the top of the cake is covered with striæ radiating from the centre, and is free from holes and rough projections; but if the fusion has been imperfect, the surface of the cake has a honey-comb appearance, with projecting lumps of malleable iron. On an average, four out of five cakes are more or less defective. Attempts have been made in London to correct these imperfections by re-melting the cakes, and running them into ingots; but it is obvious that when the cakes consist partly of malleable iron and partly of unreduced oxide, simple fusion cannot convert them into good steel. When, however, care is taken to select only such cakes as are perfect, to re-melt them thoroughly, and tilt them carefully into rods, an article has been produced which possesses in an eminent degree all the requisites of fine steel. In the supplement of the "Encyclopœdia Britannica," article *Cutlery*, the late Mr. Stoddart, of the Strand, a very competent judge, declared "that for the purposes of fine cutlery it is infinitely superior to the best English cast-steel."

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* DINGL., Bd. 164, p. 287.

The natives prepare the cakes for being drawn into bars by annealing them for several hours in a small charcoal furnace actuated by bellows, the current of air being made to play upon the cakes while turned over before it. By this means a portion of the combined carbon is dissipated, and the steel is softened; without this operation the cakes would break in the attempt to draw them; they are drawn out by a hammer weighing a few pounds.

The quality of the steel is judged of by the designs, and by the colour of the interstices between the lines, but the best criterion is the hues of the steel.

Indian wootz steel is chiefly employed for the manufacture of sword blades; its chemical nature, as well as its physical properties, are not sufficiently known, and its high repute is undoubtedly owing to the superior quality of the wrought-iron, from which the steel is produced with great care and in small quantities only, as well as to the circumstance that the steel has been fused, and perhaps also to the presence of certain substances which have been determined by analyses. We have given some analyses of the steel on page 29, to which the following may be added :—

| | I. | II. | III. | IV. | V. | VI. |
|---|---|---|---|---|---|---|
| Carbon (combined)<br>Carbon (graphitic) | 1·281 | 0·98 | 1·125 | 1·80 | 1·300 | 1·336<br>0·312 |
| Silicon | — | — | — | — | — | 0·043 |
| Manganese | 0·218 | trace | trace | 0·14 | trace | — |
| Nickel | 0·079 | 0·01 | 0·140 | 0·16 | 0·078 | — |
| Tungsten | 0·051 | — | trace | trace | trace | — |
| Sulphur | — | — | — | — | — | 0·175 |
| Arsenic | — | — | — | — | — | 0·036 |

No. 1 and 2 are wootz regulus from Constantinople, analysed by Luynes. No. 3, the same, from Persia. No. 4, a large blade of an Indian dagger. No. 5, a Persian blade. No. 6, Indian wootz, by Henry.

Attempts have been made in England to produce steel from Indian magnetic ores; the ores were smelted for the production of pig-iron, which was then fined and cemented; but the resulting steel was not equal in quality to the Indian wootz.

The real damasked blades are said to be hardened while in a red-hot state by fixing them to a wheel, which is rapidly turned.

The following methods are more or less successfully employed to produce imitations of damasked steel:—

Luynes* wholly and successfully adopted the Indian process, by fusing soft iron together with carbon and compounds of tungsten, nickel, and manganese. The production of the damasked steel was chiefly due to the manganese, by which a large proportion of carbon was introduced into the steel, without impeding its ductility.

Bréant† produced excellent damasked steel, very similar to the real metal, by fusing 100 parts of iron with 2 parts of lamp-black, or by the fusion of pig-iron with oxidised filings.

Clouet, Hachette,‡ and Mille‖ weld hard and soft steel plates together, thus producing damasked steel which excels in flexibility, elasticity, and hardness, but it does not possess the watered designs of the real damasked blades.

At the River Don Steel Works, in Sheffield,§ cast-steel is largely made by the method introduced by Mushet in 1801, which consists in melting malleable scrap iron with charcoal and oxide of manganese in crucibles, directly, without using any blister steel. The furnaces are 288 in number, each being of sufficient size to contain two pots, charged with 100 lbs. With the whole number at work, a casting of 25 tons weight may be made, the pouring from the 576 pots being completed in five minutes. In order to keep up the supply, the pots are conveyed from their melting holes to the casting place on small barrows, instead of being carried by the tongs, as was formerly the custom. The steel produced is, to a great extent, employed in making castings for immediate use, such as railway crossings, wheels, and bells, instead of being merely run into ingots to be subsequently worked up under the hammer. The moulds used for this purpose are made sufficiently refractory by the use of a thin layer of burnt clay, produced by grinding old melting pots; this is applied immediately over the pattern, the remainder of the box being filled with ordinary moulding sand. This method of steel casting was first practised at Bochum, in Westphalia, where it is still carried out on a very large scale. Castings made to pattern, and not intended to be subsequently hammered, must be annealed, and allowed to cool very slowly.

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* Bgwkfd., ix., 225. Karst., Arch., 1 R., ix., 388, 401; xiv., 456.

† Bgwkfd., v., 392.

‡ Ibid., v., 391.

‖ Ibid., v., 160.

§ Bauerman, Metallurgy of Iron, p. 361.

## REFINING OF NATURAL, PUDDLED, AND CEMENT STEEL.

These kinds of raw steel are sometimes employed direct, but if a greater uniformity, that is to say a better quality, is required, they are previously refined. The refining may be effected either by piling and welding (shear steel), or by re-melting (cast-steel).

On page 5, we have stated that the quality of shear and cast-steel may be the same if faultless raw materials are used for their production, but, for some purposes, shear steel is preferred (page 6).

When an inferior raw material has been employed, the operation of re-melting yields a more uniform product than that of welding. The latter necessitates a greater consumption of fuel and time; the shear steel is more liable to contain intermixed slag and foreign substances, chiefly ash, which is carried along with the draught, and the result depends less on the method employed than on the skill of the workmen; the production of refined steel by piling and welding is, therefore, less safe, and not in just proportion to the expense and the good quality of the product really obtained; for this reason shear steel can scarcely compete with cast-steel. In the welding process, the oxidising reaction of the flame is a great disadvantage, causing the shear steel to become poorer in carbon; it is, therefore, advisable to refine those sorts of steel which easily lose their steely nature (for instance, some kinds of inferior cement steel, page 41), by re-melting instead of welding.

The operation of re-melting causes the combination of iron and carbon to become more intimate, so that the carbon is less liable to burn out.

For the purpose of producing steel in large masses, puddled steel is in most cases re-melted instead of being welded, as such steel requires to be perfectly sound, and, to a certain degree, uniform, properties which, in a large production, are better secured by re-melting than by welding. At Neuberg and Donnersbach, attempts have lately been made to produce greater masses of shear steel cheaply by heating large piles in reverberatory furnaces, and hammering them under a steam hammer.

Malmedie states that cast-steel produced from cement steel is preferable to that obtained from puddled steel, as it is better able to bear a variable expansion and contraction; this is chiefly important in castings of an irregular or complicated shape, part of which only are hardened, while the remaining part is left soft.

## Refining the Raw-Steel by Welding and Hammering or Rolling.

The piles for the purpose of welding the steel are formed either of square or of flat bars, 2 or 2½ inches broad and from ¼ to ¾ of an inch thick; flat bars are most commonly employed and are to be preferred, especially if they are of fine dimensions, so that the pile is formed of a greater number of bars.

If the bars are not perfectly straight, they require to be heated in open fires or in reverberatory furnaces, and then straightened under hammers or rolls.

In Styria, the piles weighing 30 or 32 lbs. are about 15 inches long and 5 to 8 inches high; their outside is formed of steel bars rich in carbon. The piles are firmly wedged in an iron hoop, which, at a later period of the process, is again removed.

In some places, Styria for instance, the re-heating of the piles is effected in open hearths like the finery hearths; one pile is placed before the tuyere whilst a second pile is submitted to a preparatory heating; the blast enters the hearth at an inclination of 8 or 10 degrees, and with a pressure of 9 or 12 inches of water; charcoal is employed as fuel. As soon as the pile attains the welding temperature, it is dusted over with finely-pounded clay or with quartz sand, in order to prevent, as far as possible, superficial oxidation and consequent decarbonisation; in this case the steel will remain hard, but if the production of softer steel is designed, hammer slag or finely divided slag, rich in oxide of iron, is thrown on the pile instead of sand or clay.

The English hollow fires employed for refining piled-up bars of cement steel 30 inches long, 2 inches broad, and ¾ of an inch thick, are heated with coke, while mineral coal is used for straightening the cement-steel bars.

At Neuberg,* reverberatory furnaces are provided with hearths of sand and with direct firing, and at Donnersbach† the furnaces are heated with waste gases of other furnaces. From 13 to 14 cwts. of refined steel are produced in 24 hours, the raw steel employed having lost 10 per cent in weight. As the heating is effected in a shorter time the resulting steel is harder, and pieces of larger section may be worked.

A Styrian re-heating hearth yields only 7 or 8 cwts. of refined steel in 24 hours, at a loss in weight of from 5 to 8 per cent, and at a consumption of about 25 or 27 cubic feet of soft charcoal per cwt. of refined steel.

As the common reverberatory furnaces are liable to promote oxidation, it is advisable to employ a smoky flame; blast under the grate is likewise advantageous, as in this case the grate may be filled up higher with coal.

Before the pile has attained the full welding heat it is withdrawn one or more times from the fire and beaten with a small hand hammer, for the purpose of consolidating it; it is then returned to the fire, and being raised to the full heat it is worked under a hammer weighing about 2 cwts., and making 180 or 200 blows per minute, with a 12-inch stroke, in order to condense the pile without materially decreasing its section; this treatment, if required, is repeated several times at subsequent heats; the pile is then drawn out to a finished bar.

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* Oesterr. Ztschr., 1856, No. 16.

† Ibid., 1861, Nos. 22, 36. LEOB., Jahrb., 1860, ix., 278.

Larger piles which are heated in reverberatory furnaces, are condensed and consolidated under light hammers, and drawn out by rolling.

The texture of the steel is modified according to whether it is rolled or hammered. The particles of the rolled steel approach a spherical shape, and this steel (coach spring steel) combines great elasticity with strength to resist an alternate bending in the direction of its thickness. Hammered steel has a finer and more compact texture, and is very different in appearance; it has a greater power of resistance in all directions, together with a greater uniformity and density. The mode of forging exerts an essential influence upon the properties of the steel, which chiefly become apparent after hardening.*

The steel thus refined is called single shear steel. It may be further refined by doubling the bar and submitting it to a second welding and hammering; the result is a clearer and more homogeneous steel. If the steel is refined more than three or four times, its density and proportion of carbon are considerably lessened. The manufacture of this steel is now limited, mechanics preferring a soft cast-steel, which is much superior when properly manufactured, and which can be easily welded to iron.

## Re-melting the Raw Steel (Casting Steel).

Although the Indian wootz-steel has been in use from a very remote period, its mode of production was not known before Buchanan's publication in 1807, and the English manufacture of cast-steel* must therefore be considered as an independent invention.

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* Bgwkfd., ix., 381, 383, 389, 394.

This invention is generally attributed to the English clock-maker, Benjamin Huntsman; Rinmann asserts, however, that the discovery was made by a German of the name of Waller, who carried on the business of gold drawer in England, and made his rolls of cast-steel. Huntsman became acquainted with this secret, and established the first cast-steel manufactory in 1740, at Handsworth, near Sheffield.

The manufacture of cast-steel was thus gradually introduced and improved, and the reason why many former trials in other countries were unsuccessful was, that the raw material, which forms the most essential part in the production of faultless cast-steel, was not judiciously chosen.

As the manipulations which belong to this production (melting in closed crucibles, casting in moulds, mechanical treatment) are almost the same in every instance, the different kinds of cast-steel depend entirely on the quality of the raw material; this therefore requires to be carefully sorted. The sorting is more easily effected with cement-steel than with the other kinds of raw steel (page 41). Cast-steel has acquired great repute, chiefly for the manufacture of tools and other fine articles requiring a combination of great hardness with strength; the demand for it is owing principally to its careful assortment, and to the possibility of producing, by re-melting, a hard and at the same time homogeneous steel rich in carbon; there is always, however, this disadvantage, namely, that the proportion of carbon which constitutes the hardness and strength of the cast-steel cannot always be determined beforehand, owing to the irregular quality of the raw material; the selection or sorting of the material must therefore be left to the practised eye of the workman.

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* The Useful Metals and their Alloys, London, 1857. Oesterr. Ztschr., 1853, pp. 29, 86, 173, 268, 277; 1854, pp. 88, 198, 367, 392. KARST., Arch., 1 R., viii., 342; 2 R., xxv., 218. DINGL., Bd. 92, p. 19. LEOB., Jahrb., iii., 307; vi., 82; xii., 62. Ztschr. des Ver. deutscher Ingenieure, 1859, pp. 266, 273. GRUNER et LAN, état présent, &c.

Cement steel and natural steel are employed for the production of the best kinds of tool steel, and puddled steel chiefly for the production of steel in large masses, but it is occasionally used for tool steel. Again, cement steel is preferred to natural steel, as it is mostly lower in price, and its degree of carbonisation may be regulated at will.

In order to produce the harder kinds of cast-steel (unweldable cast-steel) from cement steel, an addition of spiegeleisen or of coal powder is required, but in English steel works no such addition is needed, as cement steel only is worked, and this is intentionally more highly carbonised. The best English cast-steel (Huntsman steel) is produced from cement steel of Dannemora iron. When the production of softer kinds of cast-steel is designed, additions of wrought-iron, tungsten (page 33), titanium (page 35), or of manganese (page 32), either as brown-stone or in the form of carbide of manganese, are sometimes made, in order to increase the hardness and strength, or it may be the hardness only. According to Köhler, steel increases in these two properties by an addition of 2 or 3 per cent of reduced tungsten; when above 3 per cent of tungsten is added, the hardness increases whilst the strength decreases; an addition of 6 per cent renders steel as brittle as glass.

According to Heath, the reaction of carbide of manganese is chiefly purifying; Cizancourt states that a mixture of carbon and brown-stone reacts favourably, as it forms carbonic oxide gas, which becomes absorbed by the liquid steel.

The re-melting of steel neccessitates the exclusion of air, and consequently the application of closed vessels, and as the temperature required (about 1900° C.) is equal to the highest welding heat, the cost of fuel and crucibles is economically of the greatest influence on the manufacture of cast-steel.

The progress made in the re-melting of steel principally consists in a greater economy of fuel; this is gained by increasing the number and size of the melting pots and also of the furnaces, but the greatest advantage is obtained by applying Siemens's regenerative gas furnaces, as by their use the consumption of fuel per ton of steel is reduced from 3½ tons of coke to 1½ tons of inferior slack.

The great importance of melting larger quantities of steel directly in reverberatory furnaces instead of in crucibles, may be seen from the following figures:—

The price of cast-steel is nearly one and a half or twice as much as that of the raw material. (If the price of cast-steel is £3 per cwt., that of noble steel will be about £2 2s., that of cement steel £1 16s., and that of puddled steel £1 10s.). The consumption of coke per 100 lbs. of cast-steel amounts to 320 lbs. in English works, to from 300 to 500 lbs. in France, and from 250 to 300 lbs. in Westphalia, to 550 lbs. at Döhlen near Dresden, to 300 lbs. at Carlswerk near Neustadt-Eberswalde, and to 660 lbs. at Sollingerhütte in Hanover. One cwt. of coke costs in England from 8·5d. to 1s.; in France from 2s. to 2s. 6d.; in Belgium from 10d. to 2s.; in Westphalia from 1s. to 1s. 9d.; in Berlin from 1s. 6d. to 1s. 8d. One cwt. of cast-steel therefore occasions a cost for coke of from 2s. 5d. to 3s. 2d. in England; from 5s. to 10s. 6d. in France; from 3s. 2d. to 4s. in Belgium; and from 2s. 6d. to 5s. 5d. in Westphalia.

The price of raw clay per cwt. in Westphalia is as follows:—English and Scotch clay from 9d. to 1s. 2d.; Belgian clay from 1s. to 1s. 2d.; Rhenish clay from 6d. to 7d. 100 lbs. of crucibles cost in Belgium 12s., and the same weight of refractory bricks 8s.

A crucible capable of containing from 30 to 60 lbs. of steel, can be used two or three times, and occasionally, though very rarely, as many as six times; 1 cwt. of steel therefore causes an expense of about 4s. for crucibles and fire-bricks. The small capacity of the crucibles likewise necessitates the employment of a greater number, which circumstance causes an increase in the cost of labour; the cost for melting and casting amounts in England, for instance, to from 3s. to 3s. 6d. per cwt.; in France from 2s. 7d. to 2s. 9d.; in Belgium from 2s. 2d. to 2s. 9d.; and in Westphalia from 1s. 6d. to 2s. 6d. The further treatment of the steel ingots involves an expense of from 3s. to 4s.

These circumstances justify the various attempts and experiments to re-melt raw steel in reverberatory furnaces with a deepened hearth and under the cover of a neutral, very liquid slag (silicate of lime and manganese). We may mention the trials made by Johnson,[*] Petit, Gaudet and Co.,[†] Barrault,[‡] and by Sudre[||] at Montataire. (See also page 201).

The majority of these trials showed the following disadvantages:—A quick corroding of hearth and furnace walls, a want of uniformity in the operation and the products, too strong a heat at the flue, and too little at the sole of the furnace. When the latter heat was to be increased, it was necessary to employ smaller charges, thus sacrificing one great advantage of the reverberatory furnace.

Barrault states that the consumption of coal still amounted to 300 lbs. per 100 lbs. of cast-steel, and the charges at Montataire could not exceed the weight of from 400 to 600 kilos.

The application of gas made from coal, and of hot blast[§] is said to enable 20 cwts. of steel to be melted in 3 or 4 hours, at a consumption of only 200 lbs. of coal per 100 lbs. of cast-steel; besides all the cost for crucibles, two-thirds of the cost for fire-bricks, and half of that for labour and tools were saved.

The difficulty of producing cast-steel of the best quality in reverberatory furnaces has not yet been overcome, and its importance has diminished since the introduction of the Bessemer process.

**Requisitions in the Casting of the Steel.**—The casting of the steel[§] forms one of the most important manipulations in the whole process, and a certain precaution is required to obtain compact and properly weldable ingots. The higher the temperature at which the liquid steel has been melted the more gas it absorbs, and on cooling it to a certain degree, the gas is given off with the appearance of more or less strong scintillations (stronger than with pig-iron, owing to the great number of burning particles of metal) depending on the proportion of carbon contained in the steel; blisters are then formed either at the end of the ingot only, or over its whole length, as on pouring the steel into the moulds the surface of the metal is more or less agitated by the evolution of gas, until the metal solidifies. Hard steel (for instance cast-steel produced from cement steel) shows the fewest pores, the evolution of the gas bubbles is not very strong, the surface of the ingot sinks on becoming solidified, till it finally bursts in the middle where a hole is formed. Soft cast-steel evolves a greater number of gas bubbles, and the softer the steel is, the more it undulates on being poured into the moulds. When cooling, the metal rises in the moulds, so that they must be covered to prevent it from overflowing. Fluid burnt iron (the intermediate product in the English Bessemer process) rises still more vigorously in the moulds.

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[*] DINGL., Bd. 159, p. 107. HARTM., Fortschr., iii., 353.

[†] GRUNER et LAN, état présent de la Métallurgie du fer en Angleterre, 1862.

[‡] B. u. h. Ztg., 1859, pp. 409; 1861, p. 407.

[||] Ann. d. Min., 6 sér., 2 livr. de 1862. DINGL., Bd, 154, p. 107; Bd. 167, p. 347. GRUNER et LAN, état présent, &c., p. 781.

[§] HARTM., Fortschr., iii., 356.

Cizancourt* has called attention to this behaviour of steel, and upon it he has founded a theory of the formation of this metal.

The reason why hard steel absorbs fewer gases than soft steel, and emits them again more perfectly, and without rising, is that the fusion point of this steel is lower; it likewise remains liquid for a longer time, and solidifies suddenly. Soft steel, on the other hand, requires a higher temperature for melting, and, on solidifying, it passes through an intermediate, that is to say, a pasty, state, which prevents the free escape of the gases, thereby causing a stronger undulation and the formation of blisters in the interior of the mass. When oxidising gases are excluded (air or carbonic acid) from the interior of the steel, it may be made sound by welding and hammering notwithstanding its blisters; this, however, is impossible if the walls of the blisters are oxidised. Steel containing a small proportion of carbon is more liable to such oxidation.

Investigators differ in the views which they take of the

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* Ann. d. Min., 5 livr. de 1863, p. 225.

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nature and manner of formation of the absorbed gases. Some assume that the oxygen of the air, which is carried into the moulds along with liquid steel or intermixed slag, oxidises the carbon of the steel or of the blackening used for coating the moulds, thus forming carbonic oxide gas. Although this effect may take place, the great abundance of the gas which, on escaping, burns with a blue flame, seems to indicate that liquid steel probably absorbs carbonic oxide gas just as oxygen is absorbed by silver and litharge.

If carbonic acid and free atmospheric air are present in the melting vessel, they also may be absorbed, thus causing an oxidation of the carbon, and even of the iron on the walls of the bubbles; the resulting steel will be softer and more full of bubbles, and cannot be rendered sound by welding and hammering. The burnt iron resulting in Bessemer's process is rich in oxygen, and not ductile.

When the degree of hardness in the steel is intended to be retained, on re-melting, carbonaceous substances must be added, and experience proves that a mixture of brown-stone with carbon (the latter in excess) is still more effective, as abundant carbonic oxide gas will then be formed, which becomes absorbed by the steel, and protects its carbon from the reaction of the gases containing oxygen. The carbonic oxide gas may perhaps be more or less mixed with nitrogen; it may possibly also come in contact with the liquid steel, as the lids of the crucibles are not hermetically closed. According to Malmedie, the nature of the crucible itself has an influence on the porosity of the steel.

Caron* maintains that cavities or honeycombs are produced within the liquid mass by the atmosphere of the furnace, oxidising iron, which, in contact with the silica of the crucible, forms a silicate, and that the silicate of iron is subsequently decomposed by the carbon contained in the steel. In order to prove this supposition, he melted steel in fire-clay crucibles, and in some cut out of a solid lump of quick-lime, as well as in others made of magnesia. He employed pieces of steel taken from the same bar. The crucibles were heated in the same furnace under perfectly uniform conditions. The steel was allowed to cool in the crucibles; these were broken when cold, and showed that the steel had in all cases been in perfect fusion; but the clay crucible had produced a rough and honeycombed ingot, while the lime and magnesia crucibles gave perfectly sound ones, moulded exactly to the shape of the vessel.

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* Köhn, Manufacture of Steel and Iron, p. 116.

In order to obtain sound castings the following precautions are observed:—

*a.* The steel is poured into the moulds at a certain, but not too high, temperature, when the greater part of the absorbed gases have already escaped. If the steel is very hot, it is poured slowly in a thin jet into the moulds; this prevents it from rising, but if its temperature is rather cool, it is poured out quickly in a thicker jet. On being cast slowly, less atmospheric air is carried along with the steel into the moulds, and time is given for the escape of the air without an undulation of the metal being produced.

*b.* The iron moulds must be suitably warmed in order to prevent too great a contraction of the steel and the formation of honeycombs, to which the high temperature of the liquid steel gives rise.

*c.* The moulds after having received the steel must be at once closed, in order to exclude the air and to mechanically prevent the escape of the gases and the rising of the metal. But in spite of this precaution, a cavity will be formed in the centre of hard steel; a better result is obtained with steel of medium hardness, but the remedy is perfectly useless with burnt iron (resulting from the Bessemer process).

Mushet* prevents the upper part of the ingot from becoming honeycombed by casting a "head" upon it by means of a clay tube.

Mr. Joseph Whitworth has patented an apparatus for subjecting steel to a high pressure during the process of casting, in order to obtain sound castings, and to do away with the necessity for great heads of metal. The process is successfully carried out at his works in Manchester.

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* HARTM., Fortschr., vi., 254.

Liquid cast-steel, on cooling, contracts and attains a peculiar crystalline texture and decreases in strength. The fracture appears granular and uneven, and when the light is allowed to fall upon it in an oblique direction, a scaly fibrous formation, in regular order, is clearly visible, the fibres running at right angles towards the outer surface.

The difficulty of obtaining an uniform casting increases with the size of the piece; well trained and experienced men are required for pouring out the metal.

The method adopted by Krupp, at Essen, Rhenish Prussia, for casting large ingots, as well as the carrying out of the same method in England, is described in a letter inserted in the "Times" of the 5th of January, 1869, of which the following is an extract:—

"Not long ago one of your correspondents gave an account of a visit to Krupp's Works. He saw the casting of a 16-ton ingot of steel, and I have reason to know, accurately described the process. The metal was melted in crucibles, as in the old and common process of casting steel in Sheffield. The organisation was so perfect, that hundreds of crucibles were ready to be taken out of the furnaces at the same time, and the molten contents of each were poured in quick succession into a common receptacle. This done, the metal was immediately let out from that receptacle into the ingot mould. At the International Exhibition of 1862, Krupp exhibited ingots of cast-steel so produced, which surprised and delighted every person experienced in the casting of steel. A single ingot weighed upwards of 20 tons, and subsequently at the International Exhibition in Paris in 1867, an ingot of much greater weight was shown by Krupp. Those ingots were not only large but sound, and it was this combination of qualities, enormous dimensions, and entire soundness which made them so remarkable.

"I have great satisfaction in informing you that similar ingots of cast-steel are now produced in our own Sheffield, and precisely in the same manner as at Essen. I have had ocular demonstration of the fact, on the occasion of a recent visit to the well-known steel works of Messrs. Firth and Sons in that town, in company with several officers of the Royal Artillery. I subjoin an account of what I there witnessed.

"The casting-house was rectangular, and along three sides were 106 furnaces with two smaller in each, the ingot mould being in the middle. Each crucible contained about 50 lbs. of molten steel.

"At a given signal the pouring of the metal commenced, and in 16 minutes the ingot mould had received the contents of the 212 crucibles. There was no bustle, no chattering, no confusion. The men—200 in number—knew their drill, and did their duty without a hitch. The ingot weighed 86 cwts., and was designed for the steel tube of an Armstrong gun. It will be observed that the receptacle employed by Krupp for receiving the steel from the crucibles in the first instance, was dispensed with, but that is only a point of minor detail. The Messrs. Firth have cast 9-ton and 16-ton ingots. A 9-ton ingot is required for the 23-ton Armstrong gun. The steel tubes are bored out of solid ingots, and this is one cause of the costliness of our modern ordnance. If larger ingots of steel should be required, they can be made at the same establishment. The enormous ingots of Krupp are to be regarded as *tours de force,* and were specially intended as such."

The writer of this letter states, in conclusion, that Messrs. Firth have expended about £32,000 in the erection of two 25-ton Nasmyth hammers, re-heating furnaces on Siemens's principle, and other appliances. The anvil block of each hammer is cast-iron, cast in one piece, and weighs 164 tons. The length of the stroke is 9 feet 6 inches.

**The Examination of Cast-Steel.**—Resch recommends the following tests for judging of the quality of cast-steel:—

1. For the determination of the *homogeneousness,* which is the most important property of cast-steel.

*a.* A well-forged piece of hard cast-steel, 1¼ inch square, is heated up to the welding heat and quenched in water; it must then throw off all its scale and appear with a clear light surface, and also be free from cracks.

*b.* The edge of a chisel for cutting stone, or any other sharp instrument made of hard cast-steel, must, on being used, wear off uniformly.

*c*. A flat piece of soft cast-steel, about 30 inches long, in the form of the blade of a knife, and in section of the shape of a wedge, is raised to cherry-red heat and immersed in cold water, first horizontally, its thick side first, and afterwards the whole piece is vertically dipped into the water and moved about in it in a spiral manner, the back of the piece of steel being kept in front. On becoming cool the steel should not be warped, and if such is the case, it must admit of being perfectly straightened without breaking, when raised to higher temperature.

*d*. A piece of cast-steel is raised to a yellow heat and allowed to cool slowly; it is is then notched, and a piece is broken off by means of a heavy hammer, when the fracture must be perfectly uniform in texture, in hard as well as in soft steel. As the grain of inferior non-uniform steel may be rendered fine by a great deal of hammering, this test requires the steel to be previously heated and cooled slowly.

*e*. Two pieces of steel, one forged in a flat and rectangular, and the other in a prismatic shape, are heated to bright redness and cooled quickly, when their surface must be free from cracks.

*f*. Upon dipping a well-polished piece of steel in dilute hydrochloric acid, and again cleaning its surface, the texture must be perfectly uniform. In non-uniform steel the hard parts attain a darkish tint sooner than the soft ones.

2. For the determination of the strength and tenacity:—

*a*. A rolled bar of cast-steel, for instance, is hardened when heated to light redness; when cold, one of its ends is notched and sharply broken off; the fracture must then show a uniform fine-grained texture. The original unhardened as well as hardened steel, when heated up to purple colour and afterwards allowed to cool slowly, must show a fine lamellar texture, and not a light and fibrous one. Coarse, and even scaly grains indicate a friable steel; steel of little strength and tenacity shows short coarse fibres, with angular grains, instead of the fine lamellar texture. A fracture that is not clearly grey, but white and glittering, indicates that the steel is approaching wrought-iron.

*b*. When a piece of hard cast-steel is heated up to a yellow heat, and hammered until it glows but slightly, the piece must remain sound, without breaking asunder or cracking at the edges. If hard cast-steel admits of hammering at a yellow heat, and becomes unsound as soon as the temperature sinks to red heat, the steel is *red-short;* and it is *cold-short* if, on hammering at a further decrease of temperature, it cracks at the edges. Soft cast-steel forged out at a yellow heat must remain sound when bent and hammered together.

*c.* Soft cast-steel is the more ductile if it can be rolled out to a great breadth in proportion to its thickness; and the more elastic, the shorter the radius of the curve to the thickness of the steel bar, if attempts are made to bend a very thin bar into a semicircle.

3. For the determination of the natural hardness of the steel, and of its property of hardening, combined with the requisite elasticity:—

*a.* The natural hardness which cast-steel attains in the process of its production depends on the proportion of carbon, and again, is intimately connected with the degree of hardness which the metal attains on being subsequently heated to a suitable temperature and quenched. The *best hard cast-steel* attains its appropriate hardness by being heated to a light red heat (rose-red) and then quenched, whilst *soft cast-steel* acquires its greatest hardness by being heated up to cherry redness. The common, unreliable, hard cast-steel requires to be heated from light redness up to yellow, and even to welding heat, in order to become sufficiently hard. The best soft cast-steel which attains no great hardness, but on the other hand, great tenacity and elasticity, is quenched in water whilst at a cherry-red heat, and even at the lower brown heat.

*b.* Hard cast-steel is forged into a turning tool, one end of which is fashioned to a right angle by a prolonged hammering; this treatment is continued until the steel ceases to glow, when it is quenched in water. The sharp end of the tool is now ground and the steel hardened at a red heat; it must then be able to attack a hard roll without breaking off, or without the edges becoming blunt. The other end of the same steel is then formed into a sharp edge without wet hammering and forging; it is hardened at a cherry-red heat and ground; the edge must then neither wear nor break off easily, in cutting either grey cast-iron, common wrought-iron, or unhardened steel.

*c.* A somewhat flat piece of steel but little hammered or rolled (as an inferior cast-steel on strong hammering becomes denser, attains a finer grain, and then requires a lower temperature for being hardened), is formed, when hot, into a cutting chisel of acute angle; it is heated to a brown heat and hardened, attaining on the edge only just sufficient hardness to attack wrought-iron, and to allow of impressions being made on the edge by means of a hammer without breaking the edge off. The chisel hardened at cherry-red heat must be capable of cutting hard cast-iron without breaking off its edges.

*d.* On hardening, steel usually requires to be heated up to rose-red and cherry-red heat, and a practised eye is required to determine the proper temperature. The following rules must be observed in this operation:—As a hollow fire allows the blast to react upon the steel, only small coal of uniform size must be used for firing, and this coal must be in full ignition at the same time in order to heat the article quickly and uniformly; when pieces of complicated size are treated, the thickest parts must be heated first, and when large and long pieces are heated they must be carefully and uniformly moved to and fro in the fire. The heat required for hardening with its characteristic colour, must show itself in the fire whilst the place is in a sort of twilight; the water employed for hardening must not be below 0° C., and its quantity must be proportionate to the size of the steel article, so that it does not become too warm, and bulky enough to well enclose the article to be hardened, as small quantities of water are liable to be repelled by the formation of steam. No complete hardening takes place if the article to be hardened is thrown on the bottom of the vessel which contains the water, owing to the contact between the article and the vessel.

*e.* On heating the hardened steel, the five known tempering colours may be observed with the increase of the temperature, namely, yellow (very pale, pale straw, and full yellow) dark yellow or brown, purple, bright blue, and dark blue. In treating hard cast-steel, only the first or second temper colour must be employed in order to obtain the suitable degree of hardness and tenacity, as the application of the higher temper colours, up to dark blue, is injurious, causing the hardened article to be little relied on. With soft cast-steel, the higher temper colours may be employed.

In order to be able properly to judge of the purpose and nature of the temper-colour of steel, the article must be brightly polished, and uniformly heated in a good fire fed with small equal sized pieces of coal, and the temper-colour must be perceptible even in the fire.

## Materials for the Manufacture of Cast-Steel.

1. **Raw Steel.**—The most desirable material for the manufacture of steel for tools and instruments, is *cement steel* produced from superior wrought-iron, and this for the reasons stated on page 235; the desired quality of cast-steel may be produced from cement steel, according to its proportion of carbon, without the application of special fluxes.

Well-assorted finery steel (page 36) may yield a product of equally good quality, but, in order to produce the different sorts of harder and softer cast-steel, an addition of wrought-iron, carbon, or very pure white pig-iron is required.

**Puddled steel** forms the chief material for the production of large castings, or of cast-steel for machinery; it may also by itself yield the better qualities of cast-steel, and, when melted with an addition of natural steel, may afford a very good tool steel.

The hardened steel bars, about ¾ of an inch square, are broken into pieces 8 or 10 inches long, and sorted according to the appearance of their fracture and surface. Natural steel (page 41) is more difficult to assort than cement steel,* which, when taken from the bottom of the cementation pots, is of coarser grain than the bars lying on the top; the higher its state of carbonisation, the whiter and duller the cement steel is. A bright bluish fracture indicates a low degree of carbonisation. Steel containing many blisters usually indicates that the bars used for cementation had been badly forged out, as the larger amount of slag facilitates the formation of carbonic oxide.

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* Oesterr. Ztschr., 1864, No. 16.

The assorted short bars of steel are broken into pieces 2 or 3 inches long, by means of a heavy mallet, the bars being laid into the grooves of a cast-steel anvil, which correspond to the section of the bars; sometimes, also, longer pieces are placed vertically on the walls of the crucibles.

2. **Fuel.**—In melting steel it is not only necessary to produce the required temperature, but to produce it as rapidly as possible, as the fusion does not take place before it is attained.

Soft steel requires a higher heat than hard steel which is richer in carbon; the quality of steel desired exercises, therefore, an essential influence on the consumption of fuel, as well as on some other points.

Owing to its high pyrometric effects, **Coke** is most commonly employed as fuel. The coke must be compact, with but little small coke intermixed, and as free as possible from ash. When blast is employed under the grate of the air draught furnaces, combustion takes place less uniformly than when draught only is applied, as the grate is more liable to become obstructed by slag, is more difficult to clean, and the slag may form a sort of tuyere conducting the blast against the crucibles, and thus corroding them. In a new furnace from 250 to 300 lbs. of coke per 100 lbs. of steel are consumed, and 325 or 350 lbs. of coke in a furnace which has become much enlarged by use.

**Charcoal** was formerly generally employed in Austria.* When draught only is employed, it is difficult to produce the required temperature, but this may be effected with a considerable economy in fuel when hot blast is applied under the grate. From 200 to 226 lbs. of pine-wood charcoal per

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* Vordernberg. Jahrb., 1843, iii.; 1846, vi. LEOB., Jahrb., 1857, vi., 86. GRUNER et LAN, état présent, &c., 1862, p. 760.

100 lbs. of steel were consumed, and 150 or 175 lbs. only, when the operations were continued for a week.

**Bituminous Mineral Coal**, poor in ash, has been advantageously employed in France* for the last few years, blast being applied under the grate, but the flame must be conducted round the lower part of the crucible by a suitable construction of the flue, as, otherwise, unmelted lumps of steel will remain at the bottom of the crucible. Firing with mineral coal admits of a greater number of crucibles, the manipulation is less troublesome, and the waste heat may be employed for the production of steam. One pound of melted steel consumes from 3·2 to 4·5 lbs. of coal.

**Brown Coal** in a raw state has not yet come into general use, although it proved successful in some experimental meltings. **Wood** likewise is never employed as fuel, as at least double the quantity would be required to produce a similar effect and in the same time as the necessary amount of mineral coal.

**Combustible Gases** produced from anthracite were employed at Allevard in France,† and gases produced from coke at Firminy in France, but without good results being obtained, owing to the difficult conduct of the generator.

The problem of employing gas as fuel for the purpose of melting steel in crucibles, has been successfully solved by the application of Siemens's regenerative gas furnaces. By their use the consumption of fuel per ton is reduced from 3½ tons of coke to 1½ tons of inferior slack. At Mayr's Works‡ in Leoben, the generator is fed with brown coal, 2 or 3 cwts. of which are consumed per cwt. of ingot. At Döhlen, near Dresden, from about 9 to 11 cubic feet of brown coal per cwt. of steel ingots are consumed.

The following substances are sometimes employed as additions :—

*a*. **Charcoal** in small pieces, from which the easily combustible dust is separated by sifting. It is employed for the production of the harder kinds of steel which are more easily fusible but less weldable. Graphite* has likewise been employed as a carbonising agent. The quantity of carbon to be added depends on the quality of the raw steel, which is determined by the appearance of the fracture, &c., and on the nature of the intended product. Experience is the only guide for fixing that quantity. At Sollingerhütte in Hanover, an addition of 1-120th to 1-90th of birch charcoal is given to natural steel, according to whether the production of weldable or non-weldable cast-steel is intended. The former can be better and with less difficulty welded to iron than English cast-steel; it forms fine and durable edges. Unweldable steel has proved itself to be excellent for all kinds of cutlery, but it is not fit for files, which are liable to fly if made too hard.

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* GRUNER et LAN, état présent, &c., 1862, p. 753.
† Ibid., p. 766.
‡ TUNNER, LEOB., Jahrb., 1863, xii., 71.

*b.* **White Pig-Iron** is used for the production of the harder kinds of cast-steel; if a large quantity of it is added, the injurious influence of the foreign admixtures which the iron may contain, becomes more apparent.

*c.* **Wrought-Iron** is used in addition for the production of softer steel.

*d.* **Tungsten** (page 235), **Manganese** (page 235), and **Heath's Carbide of Manganese** (page 235), are added to increase the tenacity and hardness of the steel, or the hardness only.†

Talabot and Stirling‡ melt brittle cement steel containing too large a proportion of carbon, with an addition of metallic oxides (oxides of iron, zinc, and manganese) in variable proportions, in order to produce cast-steel of certain qualities.

## Apparatus and Accessories.

These are chiefly:—

1. **Melting Furnaces.**—The oldest furnaces used in England about the middle of the last century were air furnaces fed with coke, and constructed so as to contain one crucible. About the year 1750 they were enlarged, chiefly by Clouet, Chalut, and others, and made capable of containing up to four

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* Oesterr. Ztschr., 1856, pp. 245, 414.

† Caron, in Dingl., Bd. 172, p. 43.

‡ Dingl., Bd. 132, p. 201.

crucibles. Till 1830, coke furnaces of the English construction, and capable of containing two crucibles each, were used in France, whilst in Austria charcoal furnaces were employed till about 1840; and, in order to economise in fuel and melting cost, the furnaces and the number of crucibles were enlarged, hot blast was employed under the grate, and the waste heat was utilised. In 1851, firing with mineral coal and the application of blast at the same time under the grate, was introduced into France. The furnaces were gradually increased, so as to contain six, eight, and ten crucibles. These crucibles are not brought into direct contact with the fuel, but are arranged in series in a chamber which is heated by a fireplace similar to that of a reverberatory furnace. The chambers are covered with a square lid in the usual way.

Siemens's regenerative gas furnaces, the arrangement of which is somewhat similar to that of the regenerative puddling furnaces, are usually constructed so as to be capable of containing about 20 crucibles.

It has been mentioned on page 237, that reverberatory furnaces have recently been experimentally employed instead of crucible furnaces.

The crucible furnaces may be classified according to the fuel used for firing:—

*a.* **Charcoal Furnaces.**—The older draught furnaces used in Austria were 1 or 1·3 metres square in section, and 0·65 or 0·66 metre high, having a chimney from 12 to 13 metres high, and 0·35 or 0·40 metre square in section. They were capable of containing nine crucibles 0·45 metre high and 0·18 metre wide in the interior, with a capacity of from 16 to 18 kilos. of steel. 10 or 12 lbs. of charcoal were consumed in melting 1 lb. of steel, and eight or nine parts of charcoal when furnaces containing from fifteen to twenty crucibles were employed.

The consumption of fuel has been decreased to 200 or 226 lbs. when the furnace is kept in operation during the daytime only, and to 150 or 175 lbs. per 100 lbs. of steel ingots when the furnace is in constant operation day and night during the whole week. This economy in fuel has been caused by the application of Müller's grate, which is an iron plate provided with 28 holes, each ¾ of an inch wide, placed instead of the grate bars, as well as by employing hot blast of 8 or 10 lines pressure, and of 100 to 280° C. temperature under the grate, and by using the waste heat for previously warming the charged crucibles and the air for combustion (at Hirschwang, near Reichenau, for instance). The furnaces contain six or seven crucibles, placed on three different places of the furnace chamber upon supports, on which powdered clay is thrown. Some of the furnaces have a roof formed of boiler plate coated inside with fire-clay.

*b.* **Coke Furnaces** capable of containing from one to four crucibles. The consumption of coke decreases in the proportion of 6—5; 5·3—4; 2·5—1·8 per 1 of steel, according to whether furnaces with one, two, or four crucibles are employed; but, on the other hand, the larger furnaces with four crucibles have this disadvantage, namely, that the air passes through the grate with less regularity. This causes the crucibles to waste sooner, and necessitates the attendance of more skilful workmen. In order to induce an uniform combustion all over the grate on the application of four crucibles, one part of the grate bars is made of smaller dimensions than the other, thus causing the different grate bars to leave interstices of various widths for the admission of air. The crucibles, when used in double furnaces, that is, in furnaces constructed for two crucibles, which are employed in most cases, last for two or three meltings, whilst, when used in quadruple furnaces, they last for two or two and a half meltings only, and the loss in crucibles increases from 1 to 3 per cent if furnaces containing more than four or five crucibles are employed. The application of blast under the grate has not removed this disadvantage (page 247).

Gruner and Lan* have calculated the melting cost per 1000 kilos. of fused steel, when furnaces containing one, two, and four crucibles are employed; these cost from 203 to 250 francs, 160 to 195 francs, and 131 to 172 francs respectively. The higher figures relate to the production of soft steel poor in carbon, and the lower ones to that of hard steel rich in carbon. The loss in crucibles of 2 or 3 per cent may be more than counterbalanced by the saving in fuel when an inferior cheaper kind of cast-steel is to be produced; but this is not possible in the production of the superior sorts of steel, and, therefore, in the larger steel works double and quadruple furnaces are employed together, according to circumstances.

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* Gruner et Lan, état présent, &c., p. 752.

The steel melting furnaces* of square or oblong section are frequently somewhat contracted on the upper part; their grate is formed of five, six, or more grate bars; their height from the grate up to the flue is usually 0·8 metre, and 1 metre from the grate to the furnace mouth, whether the furnace is constructed for one or for four crucibles. Furnaces for one crucible are in section about 0·4 metre square, those for two crucibles are 0·42 metre long and 0·55 metre broad, and furnaces for four crucibles are of an elliptical shape and 0·55 metre long and from 0·55 to 0·6 metre broad. The chimney for one furnace is from 10 to 12 metres high, and of square section 0·4 metre wide; it is provided with a damper. The flue is 0·25 metre broad, 0·22 metre high, and 1 or 1·2 metre long. The ash pit, provided with a sump containing water, must be proportionally high (2 or 3 metres) in order to facilitate the manipulations below the grate. A number of furnaces are usually built together, communicating with one common chimney (it is now and then advantageous to connect fifty or sixty furnaces with one chimney from 50 to 55 metres high), or four furnaces which are built in connection have special chimneys, the four chimneys being built together, and cooled by vertical channels, to which the air is conducted by one common larger channel.

The newer furnaces in Sheffield are 3 feet high, square in section from top to bottom, and 3 feet 6 inches wide. The flue, of 9 inches height, lies 1 foot 8 inches above the grate, and leads first in a horizontal direction, afterwards rising in the form of a staircase to the chimney, 15 inches wide and 45 feet high above the flue. The ash pit is 6½ feet high.

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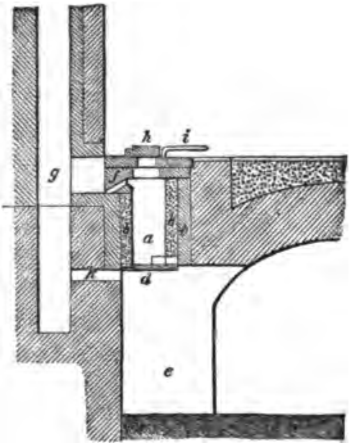
* PERCY, Metallurgy, ii., 831. DINGL., Bd. 92, p. 23, tabula ii.

A furnace of this kind is represented in Fig. 37. *a* is the furnace shaft or "*melting hole*," of oval or oblong section with rounded corners, constructed to contain two or four crucibles; the lining is formed either of fire-bricks about 6 inches thick and surrounded by less refractory bricks, or of a refractory mass, *b*,* which is firmly beaten down round an elliptical templet; between this lining and the rough walling an open space is sometimes left, which is filled up with material consisting of bad conductors of heat, or the lining is joined directly to the walling, *c*. The lining is sometimes surrounded with an air channel for the purpose of cooling. *d* is the grate; *e*, the ash pit; *f*, the flue; *g*, the chimney; *h* is the furnace lid, consisting of plates of refractory clay which are enclosed by an iron frame; the cover is provided with the handle, *i*; *k* is a channel for regulating the draught. The furnace mouth lies in the level of the sole of the smelting works.

FIG. 37.



The furnace, represented in Fig. 38, is used in Sollingerhütte in Hanover. *a* is the furnace shaft; *b*, the grate, formed of eleven grate bars, five of which are in section

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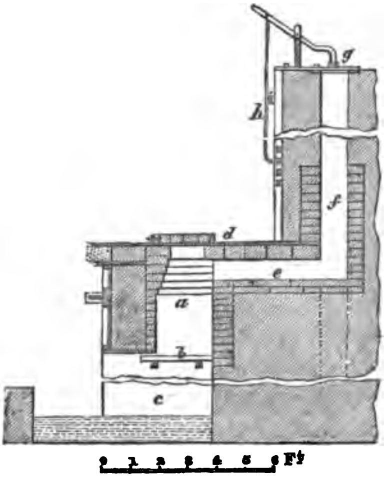
* B. u. h. Ztg., 1862, p. 248.

1⅝ inches square, and the other six ¾ or 1 inch square. *c* is the ash pit, whose sole is provided with a channel containing water; *d* is the cover formed of fire bricks, screwed together in a cast-iron frame, and provided with two rollers for moving it in a horizontal direction; *e* is the flue; *f*, the chimney; *g*, the damper, moved by the rod, *h*. A vertical air channel is constructed on the side of the chimney.

FIG. 38.



The use of the waste heat for the production of steam economises fuel, but, on the other hand, it is liable to impair the draught.

Jackson* has constructed a double furnace, provided with a common ash pit, conducting blast under the grate and employing the waste heat. This construction is said to be cheap, accelerating and facilitating the process, economising in labour and fuel, lessening the loss of steel, and improving the product.

*c*. **Furnaces Using Mineral Coal as Fuel.**—These furnaces† were first tried at the commencement of the present century; they were of the form adopted in glass furnaces. Two crucibles were placed on each of the two sides of the fire place, which were provided with an arched roof, and the gases escaped on the two long sides of the furnace. The inconvenience of placing the crucibles sideways in the furnace, as well as the large consumption of fuel, induced Clouet to employ reverberatory furnaces with a grate on one side, and to conduct blast under the grate, thus admitting of an enlargement of the furnace hearth, and an increase of the number of crucibles, without enlarging the grate; the crucibles can be placed in the furnace through openings in the roof, or through one side of the furnace. In order to heat the crucibles uniformly, and especially sufficiently at the bottom, the fire bridge between the grate and hearth is done away with, the flue is placed in the level of the hearth; and the corners of the hearth and the flue, as well as the combination between the grate and hearth, are constructed so as to form parabolic curves, which cause the heat from the furnace walls to be reflected on the crucibles. The escaping flame is frequently employed for the production of steam, but in this case, a space partially filled with refractory substances is provided between boiler and flue, in order to prevent too great a radiation of heat through the flue. By this means the fusion in all the crucibles, in those standing near the flue as well as in those on the opposite side, takes place at the same time.

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* HARTM., Fortschr., i., 455.

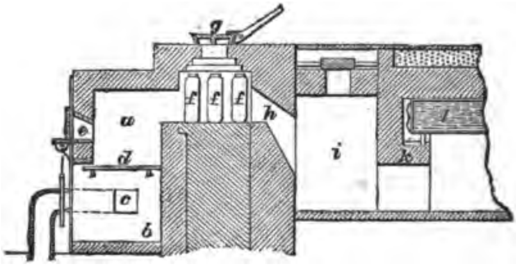
† GRUNER et LAN, état présent, &c., p. 753. Siderotechnik von HASSENFRATZ, 1812.

Clouet's furnace has the following dimensions:—Height of the roof above the grate, 0·95 metre; above the fire-bridge, 0·4 metre; above the working door, 0·3 metre; above the hearth sole, 0·65 metre; height of the crucibles with lid without supporters, 0·6 metre; height of the flue, 0·38 metre. The grate is 0·75 metre square, the hearth 1 metre broad, and 1·1 metre long; the ash pit is 1 metre high, and the tube for conducting the blast under the grate 0·2 metre wide; the pressure of the blast is from 0·008 to 0·012 metre mercury.

Jullien, Bouché, and Ballefin have more or less modified this construction of the furnace.

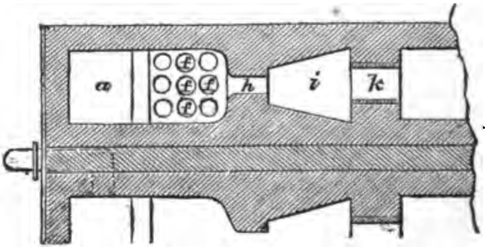
The furnace constructed by Jullien, at Lorette (Loire) is represented in Figs. 39 and 40. *a* is the fire-place; *b*, the ash pit, containing the tube, *c*, for introducing the blast; *d* is the grate; *e*, the stoking-hole; *f*, the crucibles standing somewhat low, upon a sole of quartz; *g*, is the furnace lid; *h*, the flue; *i* is the space filled with refractory substances (bricks, quartz, &c.), in order to diminish the irradiation of heat through *h*; the wall, *k*, serves the same purpose. *l* is a boiler tube. The escaping flame plays first round the boiler tube, afterwards round the boiler above that tube, and is let downwards into a channel, which leads the products of combustion into a chimney that serves for twenty furnaces.

FIG 39.



1-80th of natural size.

FIG. 40.



Jackson* has suggested different constructions for furnaces containing a larger number of crucibles, eighteen for instance.

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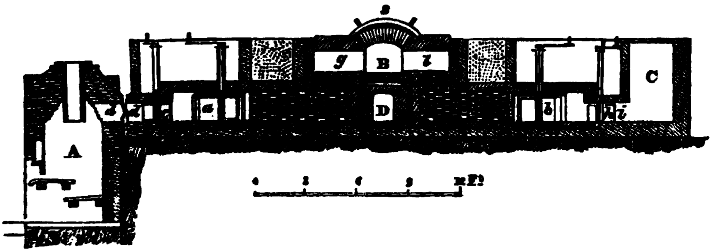
* HARTM., Fortschr., 1858, i., 461.

A comparison of coke furnaces with those fired with mineral coal shows that the economical advantage of the latter is but very small in furnaces containing two crucibles, and still less so in those containing four crucibles. The mineral coal furnaces, with more skilful workmen, give rise to a more imperfect utilisation of the heat, and to greater expense for repair; the cost also of the first plant is higher than that of coke furnaces of the same capability. The coal furnaces, on the other hand, preserve the crucibles better (the crucibles last four or five meltings, and only about two and a half or three in coke furnaces), and the production is certainly larger (by 36 or 40 cwts. in each operation); these furnaces are therefore preferable to coke furnaces in large establishments intended to produce heavy castings.

Jullien has calculated the melting cost per 100 kilos. of steel, produced in coke furnaces containing two and four crucibles, and in coal furnaces with nine crucibles, to be 20·85, 17·00, and 15·75 francs respectively.

*d.* **Furnaces Heated with Gas.**—Since 1857 Siemens's regenerative gas furnace has been employed with considerable advantage. A simple construction of this furnace is represented in Figs 41 and 42. By means of the valves represented in position at *a* and *b*, the combustible gases, produced in the generator, A, enter into the channel, *d*, provided with the register, *c*, and thence enter the space, *e*; on passing through the regenerator, *f*, filled with hot stones, they are heated; they then enter the space, *g*, and afterwards the hearth, B, which contains about twenty crucibles. The

FIG. 41.



combustion air passes from the space, C, into the channel, *i*, which is provided with a register, *h*; the position of the valve, *b*, as represented, conducts the air through the space, *x*, into the regenerator, *k*, where it is heated; it then enters through *l*, into the hearth, B, where it meets the combustible gases, thus forming a flame. The flame passes along the hearth, on the end of which it is distributed towards both sides. One part of the hot gases then passes through *y*, into the regenerator, *m*, heating it, and descending into the space, *n*, whence it passes into the channel, D, through the channel, *o*. The channel, D, communicates with a chimney 58 feet high. The hot gases on the other side of the hearth, B, pass through *z*, into the regenerator, *p*, thence through the space, *q*, and the channel, *r*, into the main channel, D. As soon as the regenerators, *m* and *p*, are sufficiently heated, the valves, *a* and *b*, are so placed as to conduct the combustible gases from A, and the cold air from C, respectively, through the regenerators, *p* and *m*, on the hearth, B. The roof, *s*, covering the hearth, is constructed in different movable parts, for the purpose of introducing the crucible into the furnace.

FIG. 42.

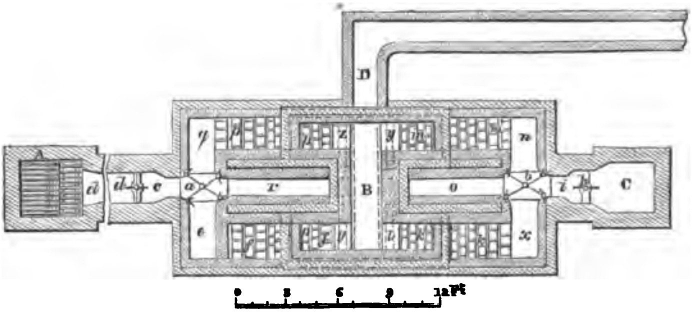
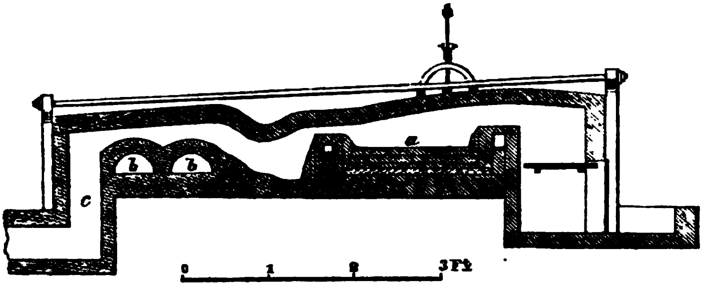


Fig. 43 represents a reverberatory furnace in which steel was melted experimentally at Montataire, without the application of crucibles. The furnace hearth, *a*, is inclined towards the fire-bridge; the two muffles, *b*, are employed for a preparatory heating of the melting materials. The flame descends through *c*, into the chimney. In order to produce the high temperature required, when employing mineral coal as fuel, it is necessary to employ blast of 300° C. under the grate, a very low roof above the hearth, and to construct the area of the grate and hearth in the proportion of from 1 or 1·6 to 1 or 3.

FIG. 43.



2. **Crucibles.***—As the crucibles exert an essential influence upon the economical result of the process, and as they are alternately submitted to very high and comparatively low temperatures, they must be manufactured with the very greatest care. They must be as refractory as possible, on cooling they must not crack; they must be strong and compact, and be composed of materials which do not impart injurious or modifying substances to the steel.

According to Bischof,† those refractory clays are most adapted for crucibles intended for melting steel which are richest in alumina, with but very little sand intermixed, and which contain the least amount of substances liable to form a fusible compound with the alumina. It is not silica, but alumina, which constitutes the refractoriness at the highest temperatures. The alkalies are most liable to impair the refractoriness of the clay, then follow protoxide of iron and lime; magnesia is least injurious. Watering clay for a longer time renders it more plastic, homogeneous, and refractory, as alkalies, as well as a great part of the silica, are extracted in a soluble form, and the clay therefore becomes richer in alumina.

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* ERDM., Journ. f. ök. Chem., ii., 108, 299; xiii., 363. B. u. h. Ztg., 1845, p. 433; 1862, p. 116. Oesterr. Ztschr., 1856, p. 245.

† ERDM., Journ. f. pr. Chem., Bd. 91, p. 19.

In order to lessen the contraction of the fire-clay, and to increase its refractoriness, burnt clay, in the form of coarse powder, and pounded coke, charcoal, or graphite, are given in admixture. According to the nature of the clay, and the care which is taken in making the crucibles, those used in coke and charcoal furnaces last for from one to three meltings, and those in furnaces heated with mineral coal may be used for five meltings.

**The Composition used in Making the Crucibles.**—The carefully sorted and purified plastic clay is ground or pounded in an air-dry state. The dry clay is then mixed either with finely ground, heated, and sifted graphite, or with charcoal or coke which has been pounded to the size of lentils; it is also mixed with old ground crucibles, or with clay that has been burnt for the purpose. The mixture is then moistened with water.

The following are the proportions of some of these compositions:—

In England, for instance, each crucible is sometimes composed of a mixture of 5·22 kilos. Stourbridge clay, 5·22 kilos. Stannington clay, 5·43 kilos. old ground pots, and 0·05 kilo. powdered coke. According to Percy, the pots used in one of the chief establishments in Sheffield, each weighing about 25 lbs., are made of the following mixture:—

| | lbs. |
|---|---|
| Derbyshire clay from Edensor | 15 |
| Stannington clay | 7 |
| Old ground pots | 2 |
| Ground cinders | 1 |
| | 25 |

The following mixture is used in French steel works:—

| | kilos. |
|---|---|
| Rich clay | 200 |
| Burnt clay | 100 |
| Old ground pots | 50 |
| Graphite | 14 |
| Water | 63 |

At the Rhenish steel works, one part of graphite and one part of old ground pots are mixed with such a quantity of Mehlem clay as is required to render the mixture plastic. At Sollingerhütte in Hanover the mixture for crucibles consists of nine parts (by volume) of Uslar clay, fourteen parts of burnt clay, and six parts of charcoal.

Analyses of different kinds of clay fit for steel melting crucibles are given in chapter iii. of this volume.

Plumbago crucibles are also used for melting steel; they are employed, for instance, in Krupp's steel works at Essen and in Austria. Each crucible is used for one charge only, after which the material is disintegrated, and used again for making melting pots, for which purpose it is mixed with a certain proportion of fresh graphite. Graphite is said to have no carbonising action on steel.*

Caron's researches on different materials used in the manufacture of crucibles have been given on page 239.

**Preparation of the Clay used in the Manufacture of Steel Melting Crucibles.**—The superficially moistened clay is allowed to remain for about a month in a cistern or a damp place. During this time the clay is kneaded by men treading upon it, or it is beaten with heavy clubs until it has attained the uniformity and plasticity required. Sometimes also the clay is worked in kneading machines, the requisite quantity of water being added. In the former case the mass is repeatedly beaten with an iron bar and formed into oval cakes, which are rolled up into a lump. This lump is spread out again in different directions by means of a wooden pole, and again pressed together. These manipulations are for the purpose of producing a uniform mass as free as possible from air bubbles. In order perfectly to exclude the air, the clay lumps are sometimes pressed into a prismatic shape, and then cut into a number of small pieces; these pieces are thrown violently upon a cast-iron plate, thus forming a lump again; this operation is sometimes repeated. The clay is weighed out in lumps, each of which suffices for a crucible.

In England the crucibles or "pots" (Fig. 47) are usually made by hand by means of a cast-iron case or pot mould, *e* (Fig. 44), open at the top and bottom, and turned in the interior, of the dimensions of the exterior of the crucible, and by means of a plug of hard wood fitting that case, and turned of the same dimensions as the interior of the crucible. The crucible mould is provided with a loose bottom, *a*, that is, a disc of iron just large enough not to drop out at the lower or small end, and having a hole, *b*, in the centre, for the passage of the spindle with which the plug is provided.

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* Oesterr. Ztschr., 1856, p. 414. KÖHN, Manufacture of Iron and Steel, p. 117.

Fig. 44.

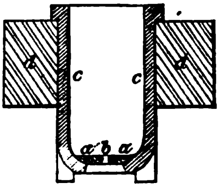


Fig. 45.

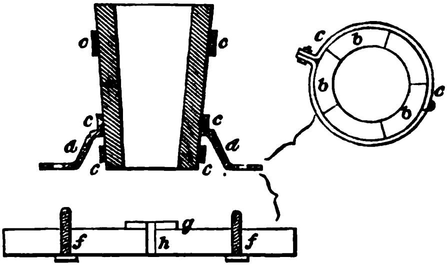
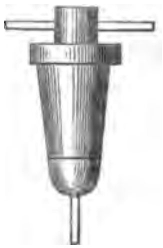
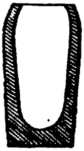


Fig. 46.



This plug is also sometimes made of iron, cast-steel, or brass. The mould is then well oiled, and placed upon a low and solidly fixed post, which has a hole in the middle, to allow the spindle of the plug to descend. The charge of clay is then put into the mould, and the plug, also well oiled, is driven down, first by hand and afterwards with a heavy mallet, the spindle at the bottom keeping it in the centre. The upper end of the plug is sometimes provided with a screw that moves in a socket. This screw has two horizontal arms ending in heavy balls, and by means of it the plug is moved up and down as in coining machines. After having scraped off the clay which may have been pressed out of the mould, the plug is withdrawn, and the edge of the crucible is loosened from the mould, thus causing a contraction of the upper part of the crucible. The pot mould is then set upon a short post, so that the loose bottom may be gently forced up with the crucible upon it. This bottom is removed as soon as the crucible has attained some consistency, the hole caused by the spindle is closed either now or later on, and the pot is then removed to a warm place.

FIG. 47.



In some smaller German steel works the crucible mould (Fig. 45) is made of hard wood, consisting of different parts, *b*, which are bound together by rings, *c*. The inside of the mould is coated with linen. The mould is provided with the ears, *d*, fixed to the middle ring, *c*, by means of which the mould is screwed to the post, *f*, when the wooden plug is driven in. The head piece, *g*, of the post, is just as large as the bottom of the crucible; *h* is the hole for the spindle of the plug.

The crucible is then formed in the manner before described. After having withdrawn the plug, the mould is taken asunder, and the crucible, surrounded with linen, is allowed to stand for a day; the linen is then removed, the crucible is polished both inside and out, the hole at the bottom is closed, and the mouth of the crucible contracted to the shape shown in Fig. 47. This contraction renders the crucibles more durable; it also enables them to be more easily taken hold of with the tongs without causing any injury. These contracted crucibles also occupy less space in the furnace, and the coke slides down on them more easily.

In Reichenau the crucibles are sometimes turned on a potter's wheel, and in Döhlen they are pressed.

The form and size of the crucibles exerts an essential influence on the consumption of fuel and loss of metal. The crucibles are usually from 6 to 10 inches wide, from 14 to 26 inches high, 1 or 1¼ inches thick at the bottom, and ¾ or 1 inch at the sides; but their size depends on the production which is intended, and also on the power of the workmen, who must be able to lift and carry them when filled. The larger crucibles are more liable to waste, and the smaller ones give rise to a greater consumption of fuel. Crucibles intended for melting tool steel, have usually the capacity of 25, 30, and 50 lbs., and those designed for large castings, of from 50 to 90 lbs. A crucible capable of containing 25 or 30 lbs. of steel, is 16 inches high, and 6¼ and 6¾ inches in diameter at the top and bottom respectively. To make such a crucible, 20 or 25 lbs. of clay mixture are required, according to whether the crucible-walls are to be ¾ of an inch or 1 inch thick.

Jullien considers that the best crucibles are those able to contain 20 kilos. of steel, and which, when charged, weigh 37 or 38 kilos., are 0·5 or 0·6 metre high, and have an outside diameter of 0·2 or 0·22 metre. When furnaces heated with mineral coal are used, the crucibles are made somewhat thicker than those which are heated with coke, as they are surrounded by the fuel, and thus acquire greater stability.

The crucibles, as they come from the moulds, are gradually heated in a moderately warm drying chamber for about 3 or 4 months; this heating is effected by moving the crucibles by degrees nearer the fire-place of the chamber.

The pots are annealed, that is gradually heated to redness, before they are put into the casting furnaces, which operation is effected either on grates by a glowing fire, or in boxes like the cementation pots, with the application of a flaming fire.

The grates are closed in by walling on three sides, and the fourth, or front part, is partially closed with a door. The crucibles are filled with charcoal or small coke, and are generally placed mouth downwards on the grate containing live coals; coke or coal is then filled in between them. The lids are placed on the bottoms of the inverted crucibles, and the stands supporting the crucibles in the furnaces are likewise distributed on the grate. The fuel is now allowed gradually to attain full heat, which takes about 6 or 8 hours, during which time the door of the ash pit is kept closed; this door is now opened, fresh fuel is added, if required, and the crucibles are raised to a light redness in from 4 to 6 hours, when they are at once transferred to the casting furnaces.

A grate of this kind is usually large enough to contain about twenty crucibles.

The cementation boxes contain about twenty or thirty crucibles, placed either sideways or mouth downwards; they are exposed to the flame of mineral coal for about 8 hours. The dry crucibles are sometimes at once provided with the charge of steel, and with lids, and about 100 such crucibles are placed in rows in a reverberatory furnace.

The waste heat of the steel melting furnaces is occasionally employed for annealing the crucibles, as at Hirschwang in Austria, for instance.

The lids and stands of the crucibles are formed in cast-iron moulds. The former are either quite solid, or they contain, on one side, a circular hole 1½ inches wide, which may be closed with a clay plug; these lids are used to exclude the air as much as possible in casting.

3. **Utensils and Tools.**—The following are those principally used:—

*a.* **Ingot Moulds**, usually made of cast-iron in two halves, which are kept together by means of iron rings and wedges. Before being used, they are warmed and brushed with coal tar, or they are smoked. For this purpose, the component halves are placed with their internal surfaces downwards upon racks, and a ladle containing burning coal tar is put underneath.

The size of the smaller moulds is 2 feet long, 2½ or 3 inches broad, and 2 inches wide; for larger ingots, at Krupp's establishment, for instance, octagonal moulds of 20 inches in diameter are used; this width is such that ingots weighing above 40 cwts. are only twice the length of their diameter, in consequence of which the metal is proportionately less cooled on the side walls of the moulds, and remains liquid for a longer time.

Mayr, in Bochum, has employed moulds of a refractory clay mass* for castings of complicated form. Former attempts with such moulds were not successful, owing to the difficulty of obtaining a material which offered sufficient resistance to the high temperature of the liquid steel, and, at the same time, to the contraction of the casting.

*b*. Tongs, differently constructed according to the purpose for which they are intended, as for lifting, pouring, &c., are used. A funnel-shaped gutter of sheet-iron 3 feet long, and tapering from 7 or 8 inches to 5 inches, provided with a handle, is used for introducing the steel into the crucibles. Other minor tools are also employed.

4. **Furnaces for heating the steel ingots for the purpose of forging.**—Articles of smaller size are heated in forges about 6 inches deep, provided with horizontal tuyeres; these forges are covered with an arched roof, and connected with a hearth for previously warming the articles. Articles of larger size are heated in reverberatory furnaces, which allow of a more uniform heating, and the application of a somewhat reducing flame; this is chiefly the case when gas is used as fuel.

5. **Apparatus for Condensing and Drawing-out the Steel Ingots.**—The more or less porous ingots, if of small dimensions, are treated under hammers weighing 4 or 5 cwts., but larger ingots are condensed either under lift hammers,

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* Dingl., Bd. 168, p. 208.

weighing 20 cwts., or under steam hammers, Haswell's forging press, or under rolls, and while being drawn out they are repeatedly heated under smaller hammers weighing 1 or 2 cwts., and making from 160 to 180 blows per minute; steam hammers and rolls are used for the same purpose.

Krupp, in Essen, works large steel ingots under a steam hammer weighing 1000 Prussian cwts. (49 tons 4 cwts. English), the weight of the anvil and anvil block being twenty-five times as much. One of Krupp's rolling machines has rolls 15 feet long, and produces steel plates 1 foot thick.

## MANIPULATIONS IN CASTING STEEL.

The first manipulation is the charging of the crucibles. The composition of a charge for the production of a certain kind of steel (whether the steel is to be hard and slightly weldable, or soft and weldable in a higher degree) is usually kept secret by the manufacturer. For this purpose, harder and softer kinds of steel are either employed by themselves, or are mixed together, and, if necessary, they are again mixed with carbon or white pig-iron, to render them harder, or with scraps of iron and cast-steel, to obtain a softer and more weldable product. Purifying and improving fluxes (tungsten, manganese, &c.), are likewise added, and also a surplus weight of from 2 to 4 per cent to make up for scorification.

According to Resch,* the following charges per crucible are used at Hirschwang, near Reichnau; they are arranged in the order which most nearly indicates the quality of the product, the ratio of the price, and even the proportion of the demand:—

I. 35 lbs. of hard or soft, but uniform cement steel.

II. 35 lbs. of best, sorted, hard, puddled steel.

III. 33 or 30 lbs. of good cement steel, in mixture with 2 or 5 lbs. of scraps of wrought-iron.

IV. 35 lbs. of carefully sorted, best natural steel, as uniform as possible.

V. 35 lbs. of common natural or puddled steel.

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* Oesterr. Ztschr., 1864, p. 53.

VI. 30 or 25 lbs. of common natural or puddled steel, together with 5 or 10 lbs. of steel scraps.

VII. 35 lbs. of pig-iron, wrought-iron, and steel scraps in variable proportions.

The accurately weighed mixture is put into a box of sheet-iron, provided with a conduct-tube, from which it is charged into the crucible by means of a funnel-shaped gutter (page 266); the crucibles are previously raised to a white heat in the steel melting furnaces, as they are liable to crack if they are only red-hot. An addition of coal is introduced into the crucibles before they are charged with metal. During the charging, the pieces of metal are placed as compactly as possible in the crucible, by means of an iron rod; the mouth of the crucible is then closed with a clay lid, and the furnace filled up with coke; in some steel works the coke is previously made red-hot. The furnace mouth is now closed, and the temperature raised to the strongest white heat.

In some works the steel is charged in cold crucibles; these receive a preparatory warming, and are then placed in the strongly heated furnaces.

Before the coke is completely burnt down, the furnace is once or twice replenished with fuel until the steel is fused, which, according to the largeness of the charge, will have taken place in 3½ or 4 hours and more. The workman examines the progress of the melting, by taking off the lid of the crucible and introducing a strong iron wire, when the steel must prove to be perfectly liquid. If no unfused particles of metal can be felt, the wire, being cooled and cleaned, is once more immersed into the steel mass, and on withdrawing it, it must be observed whether scintillation takes place, as compact particles of steel will stick to the wire. If the lids used are provided with an opening, closed with a clay plug (page 265), the plug is removed and the wire introduced through the opening. When the steel is found to be perfectly thin and liquid, the crucibles are kept for a short time at a high temperature, in order to render the steel as uniform as possible; a workman then lifts the crucible out of the furnace, being assisted by two other labourers, one of whom loosens the crucible from the stand and clinker adhering to the bottom of the furnace, while the other, at the same time, presses the lid on the crucible by means of a hooked iron rod. The crucible being transferred to the pouring or teeming hole, which consists of a rectangular cast-iron box let into the floor of the building, is placed upon a layer of coke dust, to prevent it from coming into contact with iron, and consequently cracking. Before pouring, the steel is allowed to cool down to a certain temperature fixed by experience, which facilitates the density of the castings.

The pouring itself must be effected with the precautions stated on page 237.

When smaller ingots are being cast, the lid is removed and placed on the crucible which has just been emptied; if the lids are provided with an opening or plug, the latter only is removed. The melter now takes hold of the crucible with the casting tongs, and, in pouring out the steel, he takes care to avoid touching the sides of the mould, which is then closed with an iron stopper fitting its mouth, also with sand, &c., in order to exclude the air, and to prevent the ingot from becoming honey-combed.

The mode of casting large ingots in Krupp's works and in Sheffield, is described on page 241.

In Krupp's works, the drawing of the crucibles* from the the furnace is facilitated by placing them on a platform, which is raised by a mechanical lifting apparatus placed below the ash pit, thus doing away with the use of lifting tongs.

The workman (puller out) on lifting the crucibles from the furnace, protects himself from the great heat by dressing in thick wet sacking, and keeping a moist sponge before his mouth.

Jackson and Gaudet† have employed centrifugal power for casting railway wheels, tubes, &c.

**Commencing a New Operation.**—After having emptied the crucibles, they are turned mouth downwards, cleaned on the outside from deposits, and kept in a strongly heated spare furnace, until the casting furnace is also cleaned and put in order, when the crucibles are returned into it, and, according to circumstances, the melting may be repeated in the same crucibles once or twice more in succession: the melting time will be diminished with each operation; it will decrease, for instance, from 4 or 5 hours to 2½ or 3, and in the later meltings even to 2 hours; the consumption of coke will decrease in the same proportion. But as the furnace increases in dimension, the crucible will be used each time with a diminished charge; thus, in the first charging, it may receive 45 lbs., in the second 40 lbs., and in the third only 36 lbs. The furnace is allowed to cool after three or five charges (from about 12 to 16 hours) before a new operation is commenced. In England, for instance, three charges are made in one shift, taking the time of 6, 2½, and 2½ hours respectively; at Sollingerhütte (Hanover) three charges, taking the time of 3½ hours, 3 and 2½ or 2 hours, in one shift; and in Styria five charges, taking the time of 4 to 6, 3, 2½, 2½, and 2½ or 2 hours. Operations continued for several days are only apparently advantageous, as they corrode the furnace too much, causing an increase in the consumption of fuel. A furnace requires to be thoroughly repaired after having been in operation for twelve or eighteen shifts.

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* Bauerman, Metallurgy of Iron, p. 361.
† B. u. h. Ztg., 1858, p. 277.

## Mechanical Treatment of the Steel Ingots.

The steel ingots are more or less dense, brittle, and honeycombed; they are taken out of the moulds while still hot, and if they contain seams and have grains sticking to their outside, they must be removed by means of a chisel, as otherwise, when the ingots are drawn out, these projections would give rise to the formation of cracks on the edges of the steel bars. In order to render the ingots more compact and of greater strength, they are condensed and drawn out to bars about 4 feet long, under a hammer 3 or 4 cwts. in weight, after being heated up to yellow heat; those bars that are square in section are then raised to a somewhat stronger heat, and fully drawn out under a lighter lift hammer having a quicker motion.

Larger ingots are slowly heated for a longer time (from 12 to 24 hours) and condensed under steam or press hammers, or under rolls. The ingots, on being heated, lose from ¾ to 2 per cent of their weight.

Cast-steel is also used for the manufacture of steel plate and wire.

The mechanical treatment of wrought-iron can be no guide in the treatment of cast-steel, which must be effected more carefully and slowly; and, in fact, each kind of cast-steel requires a different degree of temperature, and possesses a certain definite amount of plasticity and ductility, which, in each case, must be ascertained by experience, as any superior steel may be easily spoiled by a wrong treatment. For the purpose of condensing and drawing out, the steel is heated to a temperature between light red (rose-red) and darkish yellow; if a much higher temperature is employed, the steel commences to scintillate and burn, and becomes friable; if steel is treated at too low a temperature, or if hammered or rolled for too long a time (moreover while water is being thrown on it), it will become brittle and crack, the blows of the hammer no longer penetrate, and the drawing-out does not take place uniformly. Whilst being hammered or rolled, the temperature of the steel must not diminish below brown-redness.

## ILLUSTRATIONS OF THE MANUFACTURE OF CAST-STEEL.

### Melting Steel in Coke Furnaces.

1. **England.**—Le Play gave the first elaborate description of the manufacture of cast-steel in Yorkshire. Later communications have been made by Gruner and Lan, Heeren, and Percy.

The furnaces holding two crucibles are rectangular, 12 by 22 inches wide, and 36 inches deep from the grate to the under side of the furnace lid.

The crucibles vary in size, some holding from 28 to 36 lbs., and others from 45 to 50 lbs. of steel. The smaller charges are melted in 4 hours; the coke employed for firing is in pieces measuring from 20 to 70 cubic inches, and the steel is cast into moulds usually about 2 feet long and 2 inches thick, forming ingots, each weighing from 21 to 28 lbs., which are then repeatedly refined by being hammered or rolled. The crucibles last for three meltings, the second and third ones being effected in 3 hours. 325 lbs. of coke are consumed in melting 100 lbs. of steel.

Jullien has calculated the manufacturing cost of 100 kilos. of cast-steel:—

*a. In Furnaces containing Two Crucibles.*

| | Francs. |
|---|---|
| 108 kilos. of cement steel at 40 francs the 100 kilos. | 43·20 |
| 450 „ coke, at 2·50 francs the 100 kilos. . . | 11·25 |
| Two crucibles at 1·75 francs . . . . . . . . . | 3·50 |
| Labour at melting. . . . . . . . . . . . . | 2·50 |
| Repair of the furnaces . . . . . . . . . . | 1·00 |
| Repair of the tools . . . . . . . . . . . . | 0·40 |
| | 61·85 |
| Less 5 kilos. of refuse at 0·20 francs . . . . . | 1·00 |
| Total cost . . . | 60·85 |

*b. In Furnaces containing Four Crucibles.*

| | Francs. |
|---|---|
| 100 kilos. of steel . . . . . . . . . . . . . | 44·00 |
| 250 „ coke . . . . . . . . . . . . . | 6·25 |
| 2·2 crucibles. . . . . . . . . . . . . . . | 3·85 |
| Labour . . . . . . . . . . . . . . . . | 2·50 |
| Repair of the furnaces . . . . . . . . . . | 1·00 |
| Repair of the tools . . . . . . . . . . . . | 0·40 |
| | 58·00 |
| Less 6 kilos. of refuse . . . . . . . . . . | 1·00 |
| Total cost . . . | 57·00 |

2. **Döhlen, near Dresden.**—Furnaces containing four crucibles are used. The crucibles are made of a mixture consisting of three parts (by volume) of clay from Bautzen and Torgau, three parts of graphite from Bohemia, three parts of old ground crucibles, and one part of burnt clay. The crucibles are charged, when cold, with 60 lbs. of puddled and natural steel of Thuringia and Saxony, and after being previously heated they are exposed to the melting heat for

about 4 hours. The crucibles last for three meltings. Twenty furnaces are connected with a chimney 150 feet high, by means of two main-channels. 550 lbs. of coke, of inferior quality, are consumed per 100 lbs. of cast-steel.

3. **Krupp's Steel Works*** in Essen (Rhenish Prussia) are the largest in the world. The number of workmen employed at these works amounts to 8000, besides which, 2000 more are employed at Mr. Krupp's collieries, ironstone mines, and blast furnaces. The total production of articles of steel amounted, in 1866, to about 63,000 tons, representing a total value exceeding one and a half million pounds sterling. The steel works contain 412 steel melting, heating, and cementing furnaces; the steel melting furnaces are of different sizes, and are constructed so as to hold from two to twenty-four crucibles, each capable of containing 70 lbs. of steel.

Krupp's large ingots, as well as his mode of casting them, have been previously mentioned (page 241).

The following are the chief articles of steel manufactured by Krupp:—Tyres, which are all made of crucible steel, and according to his patent process, which consists in hammering a long square bloom to the proper size and splitting it longitudinally; the slot is afterwards widened by means of wedges and by continued hammering, until the hoop so produced can be rolled in the tyre mill to the finished shape and size. About 40,000 steel tyres are produced annually.

Rails, made of cast-steel of second quality, and sold at a price which exceeds by only 50 per cent that paid for good iron rails.

Guns, of all sizes, to a very great extent.

Also shafts, wheels, &c.

The large ingots are hammered under a 50-ton hammer.

**The Steel Works of the Bochum Company,** at Bochum in Rhenish Prussia. After Krupp's works, these are the next in importance on the Continent, and they excel in the production of perfect steel castings. At the last Paris Exhibition they exhibited, amongst other articles, a cast-steel bell weighing about 15 tons, another weighing 9 tons, and two smaller ones, all of excellent surface, and giving a very good and clear sound. The Bochum Company supply many places in Germany with such cast-steel bells for practical use.

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* LEOB., Jahrb., 1852, ii., 177; 1863, xii., 66. B. u. h. Ztg., 1857, p. 366. HARTM., Fortschr., iii., 358. Bgwkfd., iii., 224. KÖHN, Iron and Steel Manufacture, p. 213.

A specimen, more difficult to produce, was exhibited in the form of a locomotive cylinder of very intricate shape, cast in one piece of steel. The casting was quite perfect.

The Bochum Company principally apply the process of steel casting to the manufacture of railway disc-wheels and railway points, and the excellent quality of those wheels has obtained for them great repute.

**Steel Works at Sollingerhütte in Hanover.** The furnaces used in these works are represented in Fig. 38 on page 254. The crucibles are made of a mixture of fourteen parts (in volume) burnt clay, nine parts of raw clay, and six parts of small charcoal; they are 16 inches high, and 6¾ inches, 6½ inches, and 8¼ inches wide at the top, bottom, and in the belly, respectively; their sides are ¾ of an inch thick. One crucible weighs about 20 lbs., and is capable of containing from 24 to 26 lbs. of steel. The crucible lids are 1¼ inches thick.

The crucibles are kept in a hot room for about four months, and then, four of them at a time, are heated to light redness, when they are placed in the melting furnaces, which are previously heated to white heat.

The crucibles, on being raised to white heat, are charged by means of a funnel-shaped charger, 1-120th of charcoal powder being added when the production of weldable cast-steel is intended, and an addition of 1-90th of charcoal powder is made when the production of unweldable steel is designed; the furnace is now filled with coke, and the melting is finished in 3½ hours, during which time perhaps fresh coke has once or twice to be added. The resulting cast-steel is poured into cast-iron moulds, and the ingots are condensed and drawn out under light lift hammers; they are re-heated in an open charcoal fire. The crucibles last for three meltings, and the second and third meltings occupy the time of 3 hours, and 2½ or 2 hours respectively. A furnace containing four crucibles yields about 3 cwts. of cast-steel, at a consumption of from 80 to 90 cubic feet of coke. The operation of melting causes scarcely any loss, yielding 99·21 or 99·24 per cent of ingots; the loss in re-heating amounts to about 1 or 2 per cent, and that caused by the breaking of the raw steel, 0·65 per cent. 100 lbs. of forged cast-steel require 107·2 lbs. of raw steel, 33·36 cubic feet of coke, and 16·9 cubic feet of charcoal, for their production. Three meltings are made in one shift, and the furnace is repaired after having served for from forty-four to fifty-four meltings. The cast-steel produced is of excellent quality.

## Melting of Steel in Furnaces Heated with Mineral Coal.

In French steel works, at Lorette, for example, nine or ten crucibles are placed in one furnace. The crucibles are 0·5 or 0·6 metre high, and 0·20 or 0·22 metre in diameter on the outside. They are charged with 16 kilos. of steel, and heated in furnaces like those represented on page 262 in Figs. 39 and 40, which require skilful workmen to be in attendance. A melting is finished in three or four hours; five meltings are made in twenty-four hours, at a consumption of from 320 to 450 kilos. of coal per 100 kilos. of cast-steel.

Jullien has calculated the melting cost per 100 kilos. of cast-steel, in furnaces holding nine crucibles, to be as follows:

| | Francs. |
|---|---|
| 106 kilos. of steel, at 40 frs. per kilo. . . . | 42·40 |
| 333 kilos. of coal, at 1·50 frs. per 100 kilos. | 5·00 |
| 1·23 crucibles, each at 2·25 frs. . . . . | 2·77 |
| Labour. . . . . . . . . . . . . . . | 2·50 |
| Repairs of the furnaces . . . . . . . . | 3·00 |
| Repairs of the tools . . . . . . . . . | 0·40 |
| Blast and re-annealing . . . . . . . . | 0·10 |
| | 56·17 |
| Less 3 kilos. of refuse, 0·20 fr. per kilo. . . . . | 0·60 |
| Total . . . | 55·57 |

## Melting of Steel in Furnaces Heated with Charcoal.

At Hirschwang, near Reichenau, four furnaces are connected with one chimney. The shaft of the furnaces is circular, and lined with a mixture of old ground crucibles and ⅛ part of clay. The grates of the furnaces are formed of perforated cast-iron plates, under which blast of from 100° to 280° C. is conducted. Each furnace is 32 inches in diameter, and is provided with a hearth for preparatory heating 2 feet broad, 2 feet high, and 13 feet long. All these hearths run radially, so as to join in a chamber which contains a Scotch blast heating apparatus, whence the hot gases enter a common chimney. Each furnace contains seven crucibles 12 or 14 inches high, and from 5 to 7 inches in diameter. The crucibles are made on a potter's wheel, 30 in 12 hours, of a mixture consisting of 1½ parts of clay, 1 part of small coal, and 2 parts of graphite; a crucible in a dry state weighs 15 lbs.

The components of the mixture for twelve crucibles are mixed in a finely divided state for one and a half or two hours; the mass is then sifted, moistened, beaten, and divided into 12 parts. The crucibles, having been sufficiently dried in the air, are charged and placed twenty-one at a time on the hearths for preparatory heating. Each crucible is capable of containing 35 lbs. of steel, and a melting is finished in about four hours; soft steel requires more time for melting than hard steel. Six or seven different kinds of steel are produced, each requiring a different raw material (page 267), but to each charge 1-16th ounce of brownstone is added. The steel is cast in cast-iron moulds tapering somewhat towards the top; they are 10½ inches high and 4¾ inches wide. From 29 to 30 cubic feet of charcoal are consumed in melting 100 lbs. of raw steel; 100 lbs. of raw material yield 90·3 lbs. of drawn out cast-steel.

At Krems, from 25 to 30 cubic feet of charcoal are consumed for the production of 100 lbs. of cast-steel.

## Melting Steel in Siemens's Furnace.

This furnace has long been successfully employed for the making of steel in Mayr's works, at Leoben in Styria, where

3 cwts. of brown coal are consumed in the production of 1 cwt. of steel ingots. Each furnace contains twenty crucibles, and each crucible is capable of holding 60 lbs. of steel. 100 cwts. of steel are melted in six days.

At Döhlen, near Dresden, furnaces containing twelve crucibles each are used; they are charged three times a day, and each time with a total charge of 720 lbs. of steel, which is melted at a consumption of from 66 to 84 cubic feet of brown coal.

Siemens's furnace has also been adopted for the manufacture of steel by some of the steel makers in Sheffield, in lieu of the old-established coke fires. The furnace has been successfully in operation for a length of time in Mr. Siemens's steel works in Birmingham.

The following is Mr. Siemens's own description of the furnaces:—

"In the application of the system to the fusion of steel in closed pots or crucibles, the melting chamber, containing generally twenty-four pots, is constructed in the form of a long trench, 3 feet 6 inches wide at the bottom, and gathered in to under 2 feet at the top. The sides of the melting chamber are arched both horizontally and vertically, to keep them from sinking together in working, and the work is strengthened by cross walls at intervals. The pots are set in a double row along the centre of the melting chamber, and the flame passes from side to side, the gas and air from the regenerators being introduced alternately from one side and from the other, opposite to each pair of pots. The melting chamber is closed above by loose fire-brick covers, which are drawn partly off in succession by means of a lever suspended from a pulley above the furnace, when the pots are to be charged or drawn out. The pots stand in a bed of finely ground coke dust, resting on iron plates. The coke dust burns away only very slowly, if it is made of hard coke and finely ground, and it presents the great advantage of remaining always in the form of a loose dry powder, in which the pots stand firmly, while every other material that I have tried either softens in the intense heat, or sets, after a time, into a hard, uneven mass, in which the pots do not stand well.

"The process of melting carried out in this form of gas furnace, is the same in all respects as that in the small air furnaces or melting holes fired with coke which are commonly employed, but a great saving is effected in the cost of fuel, and in the number of crucibles required.

"The ordinary consumption of hard coke, costing 22s. per ton in Sheffield, is between 3 and 4 tons per ton of steel fused, while in the gas furnace the same work may be done by the expenditure of 15 to 20 cwts. of common coal slack (worth only from 5s. to 8s. per ton), at a cost of only 5s., against 75s. per ton of melted steel. There is a further saving in the number of crucibles required, as they may be used in the gas furnace four or five, and sometimes even ten times, while in furnaces heated by coke, 2 or 3 casts are as much as are ever obtained. The lining of the furnace lasts at least 15 to 20 weeks without repair (in work day and night), while 4 or 5 weeks is the longest duration of the ordinary coke fired holes."

The manufacture of the crucibles employed requires an unusual amount of attention, on account of the high temperature to which they are exposed. They are made of a mixture of ⅓ pure kaolin, ⅓ Derbyshire clay, and ⅓ Yorkshire clay from Stannington, to which a small quantity of coke dust is added. A special and very handy machine has been designed by Mr. Siemens, for the purpose of making these crucibles with a solid bottom, since the hole in the centre of the bottom, which is usual in England in the case of common steel melting pots, and which is merely stopped up by throwing a handful of sand into each crucible, is unsuitable for the high temperature of the gas furnace.

At Montataire, steel was experimentally melted on the open hearth, viz., hard steel in charges of about 7 cwts. in 4 hours, and similar charges of soft steel in 6 hours; the hearths had an area of 10 square feet, and the consumption of coal amounted to 14 cwts. per charge.

## HARDENING AND TEMPERING STEEL.

Steel has the property of becoming hard when suddenly cooled from a high temperature. The degree of hardness imparted by the operation is dependent partly on the amount of carbon, but, in a greater degree, on the difference of temperature between the heated metal and that of the fluid employed in hardening, and the rapidity with which the cooling takes place. Those fluids that are the best conductors of heat produce the greatest hardness; for this reason mercury is most efficacious, whilst alcohol is almost entirely without action. For the reasons stated on page 25 the operation of hardening causes the following modifications in the steel:—It attains a clean, smooth, silver-white metallic surface, and a grain so fine as to be no longer visible to the naked eye; it decreases in specific gravity, whilst it increases in volume (page 26), and in strength (page 16).

As these modifications become more or less apparent, according to the performance of the operation, steel is easily rendered too hard and brittle, and its elasticity is decreased if the difference of temperature between the heated metal and that of the fluid employed, does not correspond with the nature of the steel. This difference must be larger if the production of harder steel of less elasticity is intended, and *vice versa*; and it may be modified either by employing a warmer liquid for cooling, or one of higher conducting power, without changing the temperature of heating; or by raising this temperature, and employing the original liquid for cooling. The usual heat employed is cherry-redness, or somewhat below it.

In hardening steel, it is important that it should be heated up to the temperature corresponding to its nature, in order to impart to it the hardness and elasticity required for its further treatment. A great number of liquids, some of them very ridiculous, have been recommended and suggested for cooling the heated steel, but they cannot replace the experience of the workmen, and an inexperienced man is never able, in every case, to impart to the steel the desired hardness.

Steel combining the greatest hardness with the greatest elasticity, is the most perfect, and its perfection is the greater if it easily attains that hardness, or, in other words, if it only requires a low temperature previous to cooling. The temperature required for hardening decreases with the quality of steel; it is usually highest with natural steel and lowest with cast-steel, answering to the fact proved by experience, that the hardening is the more perfect the finer and lighter the grain which the steel has acquired. The hardening of cast-steel has been explained on page 245.

The difficulties accompanying the hardening of steel consist, therefore, partly in the variable quality of the steel itself, but more so in the inability to determine the degree of temperature which, in every case, corresponds to the nature of the steel under treatment. For this purpose many remedies have been proposed, but all have proved ineffectual, and the old and only one is still employed, namely, that of judging by the colour of the heated article; this requires a very experienced eye, and that even is liable to mistakes, as the colours of the same steel at the same degree of heat have a different appearance according to the time of day, the weather, &c.

The very greatest care will therefore not always enable the steel to be raised to that degree of temperature which may ensure the proper hardness and elasticity; if it does not at first become sufficiently hard, the operation of hardening must be repeated, and, on the other hand, when the steel has become too hard, thus decreasing in elasticity and tenacity, or if the steel is to be engraved, its hardness must be decreased by tempering; the higher the temperature employed, the softer the steel will become.

We mentioned the various colours in which the steel appears at different degrees of temperature, on page 19; the following table shows the articles for which those colours are considered suitable:—

| Temperature. C. | Temperature. Fahr. | Colour. | Temper of various articles. |
|---|---|---|---|
| 221° | 430° | Very pale yellowish. | Lancets. |
| 232° | 450° | Pale straw. | Best razors, and most surgical instruments. |
| 243° | 470° | Full yellow. | Common razors, penknives, &c. |

| Temperature. | | Colour. | Temper of various articles. |
|---|---|---|---|
| 254° | 490° | Brown | Small shears, scissors, chisels for cutting *cold*, hoes. |
| 265° | 510° | Brown, dappled with purple spots | Axes, plane-irons, pocket knives. |
| 277° | 530° | Purple | Table knives, large shears. |
| 288° | 550° | Light blue | Swords, watch springs, bell springs. |
| 293° | 560° | Full blue | Fine saws, daggers, augers. |
| 316° | 600° | Dark blue | Hand and pit saws. |

On slowly cooling, these temper colours appear in reversed order, and the steel is plunged into the liquid as soon as the proper colour becomes apparent.

Those articles, therefore, which require the greatest hardness are heated up to the yellow heat, and for those which require more tenacity and elasticity than hardness, the steel is heated until it attains the blue colour.

The tempering of cast-steel has been described on page 245.

For the purpose of hardening, steel is heated either in open fires, fed with charcoal or coke, or in glowing furnaces, sometimes before the blast-pipe, or in cases made of clay, plate or cast-iron,* &c.; smaller articles are sometimes heated in the flame of a candle or lamp. The re-heating for tempering the steel is generally effected in baths of molten metals, or metallic alloys, having definite fusing points. Thus alloys of tin and lead, in variable proportions, may be used up to a temperature of about 300° C; above which, boiling linseed oil and pure lead are to be employed Sometimes also the articles to be tempered are re-heated in open fires or on a heated cast-iron plate.

The heating before hardening must be effected quickly and uniformly, to prevent the formation of much scale; thus the steel will also be rendered more tenacious, and less liable to become warped than when the opposite course of heating is followed.

English cast-steel must not be heated above rose-red or brown-red heat in the process of hardening, as a higher temperature will render it too hard and brittle; German cast-steel occasionally admits of a higher temperature, but it also frequently requires a lower temperature than English steel; the steel from Sollingerhütte, in Hanover, for example, requires a comparatively low temperature to render it capable of being formed into articles with the finest edges. Shear steel must be hardened at a much higher temperature than cast-steel.*

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* Bgwkfd., ix., 422. DINGL., Bd. 105, p. 102.

In hardening steel, the nature and temperature of the fluid† employed for cooling is of essential influence. The one most commonly used is water, which renders the steel harder or softer according to whether it is more or less cold or hot. Water containing salts (saltpetre, for instance) in solution, renders steel harder than soft water, owing, it is said, to its being a better conductor of heat; this is, however, doubtful.

Greasy substances, such as oil, tallow, wax, and soap, impart to the steel a lower degree of hardness than water, as they protract the cooling, whilst hardness is increased by all acids and mercury. The above-named greasy substances are chiefly employed when a great number of thin and elastic substances, such as needles, fishing-hooks, steel pens, springs, &c., are to be hardened.

The nature of the fluids must be regulated so as to suit that of the steel, and also the degree of hardness intended. For this reason, files are hardened in slightly acid water containing some saltpetre; anvils and hammers in very cold running water; arms and cutlery in greasy substances; springs and scythes in hand warm water or in molten tallow, &c.

Articles of non-uniform dimensions, those, for instance, with a sharp edge, are liable to crack unless they are cooled in substances which are bad conductors of heat (greasy substances, moistened small coal, &c.). Cracks on the edges of the steel* may also be caused by certain impurities in the steel, such as silicon, which may be avoided in cast-steel by adding some carbide of manganese in the melting pots (page 249).

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* Dingl., Bd. 128, p. 154. Bgwkfd., ix., 420. B. u. h. Ztg., 1858, p. 622.

† Bgwkfd., vi., 336; ix., 433; xi., 478, 596. Polyt. Centr., 1847, p. 1360; 1853, p. 737. Dingl., Bd. 88, p. 54.

Large massive articles frequently fracture on hardening, owing to contraction; it is therefore advisable to previously compress such articles by strong blows under a hammer, or by pressing or rolling.

Most steel tools require to be hardened only in one part (point, edge, &c.), or perhaps in two parts; this is effected by plunging only that portion of the tool into the fluid for cooling, while the other part is used for producing the proper temper colour. This mode of hardening easily gives rise to the formation of cracks on the hardened steel, which, however, according to Rust, may be avoided by plunging the steel article inversely into the fluid, so that the part to be hardened comes last into contact with the fluid. The steel must afterwards be tempered.

Cast-steel rolls are made either of soft cast-steel, and are then hammered and forged, or hard cast-steel is at once employed, and the hardening is effected by the cast-iron mould in which the rolls are cast.

Dittmar,† in Sheffield, hardens cast-steel files in the following manner:—Refuse of leather, horn, &c., is burnt and finely pounded, and 4 lbs. of this powder is mixed with ½ lb. of pounded soot, ¼ lb. of common salt, and some potter's clay; the mixture is converted, by the addition of water, into a pasty mass, to which some vinegar or barm is added. This paste is put on the files and dried; the files are then heated and cooled in a very dilute solution of common salt; the film of oxide which has formed is removed with dilute sulphuric acid, and they are rapidly dried in hot air on an iron box.

**Hardening the Surface of Wrought-Iron.**—In order to provide the surface of malleable iron with a crust of hard steel, the iron, while heated to welding heat, is plunged into liquid pig-iron[*] and forged out; but more frequently the iron is heated with substances producing cyanogen, or it is immersed into them while in a hot state. According to Martignoni,[†] the iron is raised to red heat and coated with a mass for hardening, which consists of a mixture of five parts burnt and powdered cows'-hoofs, five parts of Peruvian bark, two and a half parts of common salt, one and a half parts of potash-saltpetre, two and a half parts of ferrocyanide of potassium, and ten parts of black soap. This mass is then burnt away in the fire, and the iron cooled by plunging it into water. Vaughan[‡] states that a fluid suitable for immersion of the red-hot iron may be obtained by fusing together twenty-five parts of ferrocyanide of potassium, sixty-five of common salt, ten of bichromate of potash, with an addition of powdered bones and animal charcoal. Johnson[‖] produced a similar fluid from a mixture of 500 parts grease, 500 oil, 550 charcoal, 250 ferrocyanide of potassium, 330 horn, and 300 saltpetre. Carré[§] suggested the following method:—The iron is slightly cemented in the usual manner, and the crystalline texture thus produced on the surface of the iron is transformed by rapidly heating the article to a temperature equal to the highest point used in cementing. For this purpose, the article is removed from the cementing boxes. It is then allowed to cool slowly by exposure to the air, when it may be submitted to the process of hardening.

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* DINGL., Bd. 133, p. 107.

† Bgwkfd., xviii., 467.

## Welding Steel to Iron[¶] (Steeling of Iron).

As many articles would be too expensive if formed wholly of cast-steel, they are frequently made of malleable iron, and steel is welded to those parts of the article which must absolutely be of that metal. As malleable iron requires a higher temperature for welding than steel, the latter is put into the fire later than the iron, otherwise the steel would be partly burnt before the iron had attained the proper temperature. In some cases the two metals are heated in different fires, the iron in a fire heated with mineral coal, and the steel in one heated with charcoal; they are then united on the anvil by quick light blows.* In welding, the steel is either placed on the iron, or in a slit cut in the iron.

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[*] Bgwkfd., ix., 126; xi., 567.

[†] DINGL., Bd. 168, p. 233.

[‡] WAGNER'S Jahrsber., 1858, p. 17.

[‖] DINGL., Bd. 158, p. 205.

[§] Ibid., 160, p. 298.

[¶] B. u. h. Ztg., 1846, p. 462; 1853, p. 901. Bgwkfd., xiii., 401; viii., 366. DINGL., Bd. 89, p. 238; Bd. 92, p. 32; Bd. 101, p. 337; Bd. 108, pp. 108, 463; Bd. 130, p. 226; Bd. 137, p. 440.

For the welding to be perfectly successful, it is requisite to exclude the air. This is effected by thoroughly cleaning the parts to be welded, and throwing sand or clay on them, or, what is still better, coating them with borax. An addition of sal-ammoniac is likewise found to be advantageous.†

It is important that the steel used for welding to iron should be of such dimensions as will still allow of being drawn out. The heating modifies the state of aggregation, but both this and the uniformity may, however, be reconstituted by the action of the hammer.

Heating the metal at too low a temperature, necessitates a too cold hammering, and thereby induces brittleness.

It is more difficult to weld cast-steel to malleable iron, than the cement steel or natural steel from which that cast-steel is produced; the hard kinds of steel, rich in carbon, cannot be welded at all. A skilful workman, well acquainted with the nature of the steel, and especially its behaviour in higher temperatures, does not require special appliances for welding it to iron. They may, however, be advantageous to one less experienced, to prevent a partial decarbonisation, and to render the welding planes perfectly clean. For this purpose, several welding powders are recommended to be thrown on the red-hot places of the articles which are to be welded together. Rust,‡ for instance, suggests a mixture of 41·5 borax, 35 common salt, 15·5 ferrocyanide of potassium, and 8 calcined soda. Hustig‖ recommends a mixture of loam and slacked lime, and Habich§ one of 7 ferrocyanide of potassium, 2 calcined soda, with a small addition of borax.

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* Bgwkfd., ii., 493.

† Ibid., ii., 493; vii., 110.

‡ Dingl., Bd. 140, p. 234. Bgwkfd., xix., 476.

‖ Polyt. Centr., 1856, p. 693.

§ Dingl., Bd. 140, p. 369.

## Regeneration of Burnt Steel.

The treatment of steel in forging is very difficult, as it is liable to lose carbon (burn) if heated too long and at too high a temperature. Burnt steel, which is friable and brittle, may be reconstituted by plunging it into carbonising agents. The following mixtures for regeneration have been made use of:—Rigaud employs 1 kilo. of sheep-tallow, 1 kilo. of unpurified linseed oil, and 100 grammes of pine-soot; Gérard, a mixture of 10 resin, 5 fish oil, and 3 sheep-tallow; Wagner, 500 tallow, 125 black pitch, 375 sal-ammoniac, 125 ferrocyanide of potassium, 75 black pepper, 30 soap powder, and 30 common salt; Schnedermann, 5 kilos. of resin, 2·5 kilos. of fish-oil, 1 of tallow, and 125 grammes of assafœtida. Werthheim's composition is especially recommended; it consists of 1 lb. tallow, ¼ lb. of black pitch, ¾ lb. sal-ammoniac, ⅓ ·lb. ferrocyanide of potassium, 1½ ounces black pepper, 1 ounce soap powder, and a handful of common salt.

Cizancourt* considers the presence of carbonic oxide to be sufficient for the carbonisation of iron; this likewise explains Malberg's views (page 22).

* Ann. d. Min., 5 livr., 1863, p. 297.

# CHAPTER II.

## FUEL.

THE term *fuel*[*] is applied to all substances which are practically employed for the production of heat.

The combustibles, or different kinds of fuel, occur either in the vegetable kingdom (wood), or in the mineral kingdom; those belonging to the latter (turf, lignite, coal), are a transformation of vegetable substances. From this raw fuel, artificial fuel, such as charcoal, coke, and combustible gases may be produced.

The kinds of raw fuel are materially composed of carbon, hydrogen, oxygen, and certain inorganic substances; in perfect combustion they yield carbonic acid and water, the inorganic substances remaining meanwhile in the form of ashes.

The following is the behaviour of raw fuel at higher temperatures:—When heated with the exclusion of air (dry distillation) the atoms of the different constituents of the fuel follow the laws of affinity, and become transformed; the oxygen will combine with the hydrogen, forming water; the surplus of these elements will then unite with carbon, forming either carbonic oxide, carbonic acid, carburetted hydrogen and oxygen compounds, &c., which compounds either escape as more or less combustible gases, or become condensed to fluids (tar, acetic acid, &c.). In no case does fuel contain so large an excess of oxygen and hydrogen as to transform all the carbon into gaseous compounds, part of it will always remain in the form of charcoal or coke, mixed with the ash-forming components, and this surplus of carbon will be the greater if the process of carbonisation has been carried on at a low temperature, or at a very gradual increasing temperature. It is the object of the process of carbonisation to produce this carbon. Ebelmen* has analysed the gases that result in the different periods of the process of carbonisation, and their composition has led him to draw conclusions on the chemical reactions of the process, and to suggest practical rules for it.

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[*] KNAPP, Chem. Technologie, i., 6. SCHEERER'S Métallurgie, i., 135. FRITSCHE, die Brennstoffe und ibre Anwendung: Neustadt, 1847. C. HARTMANN, die mineralischen Brennstoffe: Halle, 1856. TUNNER, Stabeisen und Stahlbereitung: Freiberg, 1858, p. 19. MUSPRATT'S Angew. Chemie., bearb. von STOMANN, Bd. ii., 1857.

Owing to the imperfection of the apparatus, a defective combustion of the compact raw fuel usually takes place in the metallurgical processes; the oxygen of the atmosphere combines with the most readily oxidised substance, namely, the hydrogen contained in the surface of the fuel, and the heat thus produced carbonises the interior of the compact fuel, in consequence of which combustible gases are emitted. These ignite and form a *flame*, while the remaining carbon, not being volatile, gradually combines with oxygen, producing a *glowing fire*. Fuel ignites the more readily, and continues to burn with a long flame, if it contain a large proportion of hydrogen.

The combustibility, that is, the readiness with which fuel ignites, decreases with its compactness, and increases with its amount of hydrogen, equal compactness being supposed. The compactness of the fuel exerts less influence on the length of the flame than the hydrogen contained in the fuel, which, on combining with carbon, forms combustible gases, thus producing that flame. A larger amount of ash likewise impairs the property of forming flame, and for this reason great care should be taken in the choice and construction of the fire places.

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* Bgwkfd., viii., 209; x., 161. JULLIEN in Bullet. de la Société de l'Industrie Minérale, Tom. iii., livr. 3, p. 340.

The effect of the fuel is sometimes facilitated by combustible substances contained in the ore under treatment (sulphur, bitumen).

**Fire-places.**[*]—The combustion of fuel is produced either by the assistance of *blast* or of *draught*. The former penetrates the fuel more perfectly than the latter; it admits of as perfect a combustion as is possible, and produces the highest degrees of temperature. The draught is induced by means of a chimney, and its effect depends on the perfection of the fire-place. With regard to the application of draught, the following different kinds of fire-places may chiefly be distinguished:—

1. **Fire-places without a Grate.**—The combustion takes place on a solid horizontal foundation. These fire-places are applied to the burning of easily combustible fuel in larger pieces (wood, loose turf, &c.) They allow of only a very imperfect combustion on the surface of the pieces, on account of air being admitted on the side of the fire-place, and the greater part of the air escapes without having produced any effect. The temperature produced on the outside of the pieces causes a carbonisation of the interior mass, and the products of this carbonisation, on cooling, escape plentifully as smoke, the greater part of it not being burnt.

2. **Combustion in Horizontal Grates.**—The fuel is burnt in larger pieces in a walled-in space, upon a support of iron bars (grate rods), having sufficient interstices for the admission of air to the fuel. For the reason that the air penetrates the compactly lying fuel from below, the oxygen contained in the air is more perfectly absorbed than is the case in the former kind of fire-places, and a more perfect combustion takes place on the grate. The hot products of combustion thus evolved rise along with the air poor in oxygen, and their temperature reacts upon the uppermost layers of fuel, decarbonising them; the unburnt products of combustion will

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[*] Compendium zur Wärmemesskunst und deren Anwendung von Schinz. Stuttgart, 1858. Grashof, Untersuchungen über Feuerungsanlagen, nebst Beschreibung eines Gasofens mit selbstwirkendem Regulator. Mit Rücksicht auf einen Aufsatz von Schintz. Zeitschrift des Vereins Deutscher Ingenieure, 1857, Februar. Leo, die Brennmaterialienlehre, 1860, p. 265.

then escape as smoke, which is particularly dense, when fresh fuel is thrown on the grate. This formation causes loss of fuel, and may also impair the chemical reactions of the process in operation. The loss may be lessened, however, by placing the grate in an inclined position, somewhat higher in the back, by which means the smoke and hot air will be brought into more intimate contact with each other. When longer grates are employed, larger interstices are left between the grate bars on the back than on the front part, to facilitate the admission of a sufficient quantity of air to the fuel lying in the back part of the grate.

The draught induced by a chimney has the disadvantage of being irregular and unsafe, and it likewise yields from 15 or 20 per cent of the fuel as cinders (ash containing unburnt particles of coal), which are lost to the process, as they fall through the grate into the ash-pit, and can only be used for glowing fires. This loss increases in rapid proportion with the impurity of the coal employed.

On opening the stoking-hole for the purpose of throwing fresh fuel on the grate, cold air is admitted, thus causing fluctuations of the temperature, which may be hurtful to the processes in operation.

In order perfectly to utilise the fuel on horizontal grates, many contrivances have been adopted.

*a*. Blast Under the Grate.—The ash-pit below the grate is closed, and blast conducted into it. By this means Lan* obtained considerable advantages in the process of re-heating iron, both with regard to loss of metal and to consumption of fuel; but with this disadvantage, also, that the iron was rendered impure by ash carried along with the blast, and the grate became more than usually obstructed by slag. Blast under the grate did not prove successful in the puddling of iron. This, again, was the case at Neustadt in Hanover, according to the accounts given by Langenheim† and Becker.‡

*b*. The escaping combustible and incombustible hot gases are adapted to other purposes, to the heating of blast, boilers, &c.

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* B. u. h. *Ztg.*, 1857, p. 18.

† Ibid., 1859, pp. 398, 469.

‡ Berggeist, Nos. 96 and 98, de 1859.

*c*. The smoke is consumed either at its formation by means of a more regular and uniform firing, thus causing the separated particles of coal to be burnt in the flame before cooling (by mechanically raising the fuel;[*] by constructing the grate in a basket-like form, so that the air is admitted from the sides also; by employing blast under the grate, &c.,) or the smoke, after being formed, is burnt, but still in the interior of the furnace, by a suitable admission of hot air; this must be effected before the flame has cooled too much. It has been proposed to employ hollow grate bars, and to conduct air through them, thus warming it. This air is thence admitted above the grate to facilitate the combustion of smoke.[†] Jullien's views on the combustion of smoke have been corrected by Lan.[‡]

*d*. The application of hot air, which economises the consumption of fuel. The air may sometimes be heated by constructing the grate bars in the shape of a belly downwards, thus forming between the bars a sort of heating apparatus. A grate of this construction has been used for a long time in cupelling furnaces at the Upper Hartz, and also in lead ore roasting furnaces in Schemnitz, where 5·6991 cubic feet of wood per cwt. of ore were consumed, whilst 9·3952 cubic feet were required when grates of the usual construction were employed.[||]

The air is heated in a similar manner when the slag or clinker grates are employed[§] (copper furnaces in Wales, Belgian and Westphalian zinc furnaces, &c.) By means of several iron bars, an artificial grate about 0·6 metre high is formed of the ash of the fuel, and upon this grate the fuel is accumulated 0·6 or 0·7 metre high. The air enters through channels and interstices formed in the clinker mass, where it is heated before coming into contact with the fuel. These artificial grates admit of the application of a dusty kind of fuel (anthracite, for instance), and protect the iron grate from the wasting influence of sulphur, which the fuel may contain.

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[*] Debelley, in Polyt. Centr., 1854, p. 825.

[†] Oesterr. Ztschr., 1856, p. 101.

[‡] Bulletin de la Société de l'industrie Minérale, tom. iv., livr. 1, p. 53, 1858.

[||] Oesterr. Ztschr., 1857, p. 172.

[§] B. u. h. Ztg., 1856, p. 213.

If the coal employed does not form a sufficient quantity of slag, some iron blast furnace slag, pounded into pieces not larger than a pea, is from time to time thrown on the stratum of coal.

*e.* Gas Generators.—The construction of gas generators is effected by placing a thick layer of fuel upon the grate (or by conducting blast under the grate). The fuel which lies lowest in contact with the air will then burn, forming carbonic acid, which ascends to the glowing fuel lying above, and becomes reduced to carbonic oxide; this oxide is burnt by means of the introduction of air. This method, which we purpose hereafter to describe more fully, admits of the perfect utilisation of even an inferior kind of fuel without the formation of smoke. Senger has succeeded in burning mineral coal, without any smoke, for the purpose of heating a boiler. This is done by employing two grates side by side, and separated by a partition wall. The fire on the grates is so conducted that while one of the grates contains coke, the other is filled with fresh fuel. The greater part of the air passing through the coke without being decomposed, will then burn the smoke produced on the other grate.

**3. Combustion in Müller's Fire-places (Heizpulten).**—These fire-places are of somewhat peculiar construction; the grate is formed by a perforated iron plate having holes five lines wide. The plate is placed in a slanting position inclining slightly towards the back part, and blast of low pressure is conducted under it. This kind of grate permits of the combustion of small fuel rich in ash, and is frequently employed in puddling and re-heating furnaces (at Buchscheiden for turf, at Prävali in Carinthia for brown coal, for lignite at Krems in Styria, Maximilianshütte, near Regensburg, &c.)

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[*] TUNNER'S Jahrb., 1854, p. 247; 1860, p. 346.

4. **Combustion on Step Grates**[*]—The construction of this kind of grate may be seen in Figs. 242 and 255, on pages 787 and 811 in vol. ii. These grates allow of a continual firing and the application of small fuel. The formation of cinder is almost entirely done away with, and air and fuel always enter the fire-place uniformly in a suitable proportion. The fuel lies in thin layers upon the grate perfectly exposed to the air, and no carbonisation takes place by means of the hot products of combustion. In order to produce a perfect combustion of the smoke, a horizontal grate is fre-frequently placed at the foot of the step-grate, and air is conducted under it. Owing to their simplicity, step-grates are easily employed in all fire-places; they admit of an easy manipulation, and afford a considerable saving in fuel. Bituminous coal is less adapted to them than that which is non-bituminous, as they are liable to form bulky lumps in the large fire-place, thus creating channels through which the air passes without being perfectly used. Step-grates are most successfully employed in the use of both mineral and brown coal for heating boilers, puddling, re-heating, and roasting furnaces, &c.

Vogel's furnace,[†] provided with a step-grate, through the interstices of which blast from a fan is introduced, is used with great advantage for burning very fine brown coal, and this furnace is well adapted for all kinds of finely divided fuel, supposing that a very high temperature is not required. Krafft[‡] has constructed a furnace for burning saw-dust and other fuel in powder. The chain grate is a modification of the step grate (Kettenrost); in it the grate bars are placed in the ordinary way in the position of steps, and the single grate bars are combined by Vaucanson's chain, guided by two drums. These movable grates are said to afford a saving of from 18 to 25 per cent of fuel.

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[*] TUNNER'S Jahrb., 1852, p. 246. Bgwkfd., xvi., 504; xvii., 668. B. u. h. Ztg., 1854, p. 297, 1860, p. 180. Polyt. Centr., 1856, p. 186. Oesterr. Ztschr., 1855, No. 46; 1856, No. 11; 1859, No. 49. DINGL., Polyt. Journ., cliv., Hft. 2, p. 88, 1859.

[†] Oesterr. Ztschr., 1859, No. 9, p. 65.

[‡] DINGL., cxlviii., 137; cli., 240.

Mandlay[*] has constructed a screw grate (Schraubenrost), and Langen's[†] grate, termed floor grate (Etagenrost), contains the fuel on a few broad bars placed like a step grate.

5. **Reversed Combustion in Grates.**—Differing from the fire-places provided with grates, are some which are so constructed that the combustion air is conducted downwards through the fuel from above, and the products of combustion are carried off from below the fuel. These fire-places are termed in German "Pultfeuerung."[‡] Such a fire-place, in which wood is used is represented in Figs. 48 and 49. The oblong fire-place, A, is walled in by *a*, *b*, and *c*, and contains the projections, *d*, on the small side walls, *a*, for receiving the dried pieces of wood. The space, B, to be heated, is connected with a chimney creating the draught; the chimney reacts upon the fire-place, A, by means of the flame hole, *e*. When the lower part of the wood is ignited by means of burning coal or shavings, the flame will pass through *e*, into the space, A, and heat the substances present therein. The carbonised particles of the burnt pieces of wood, which require to be continually replaced, glide down the sloping

FIG. 48.

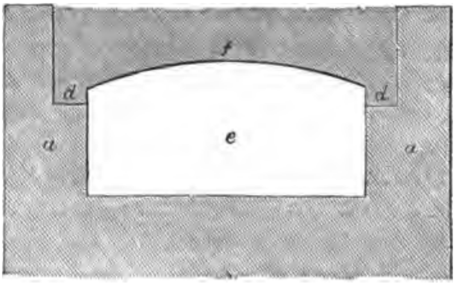
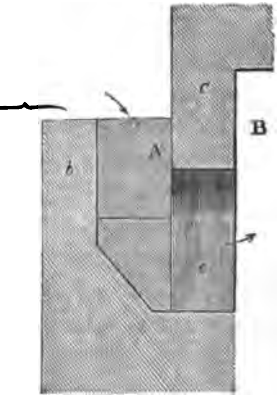


FIG. 49.



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[*] Bgwkfd., xiii., 414.

[†] Berggeist, 1860, Nos. 67, 73, 74.

[*] LEOB., Jahrb., 1858, No. 4. Oesterr. Ztschr., 1859, p. 44. B. u. h. Ztg., 1859, pp. 196, 389.

front wall, and in burning out, their products of combustion also enter the furnace, B. The ashes which collect are removed from time to time through an opening with which the fire-place is provided for the purpose. Such a fire-place admits of a more perfect combustion of the fuel, and of the production of a higher temperature than an ordinary grate. Whilst, with the latter, the hot products of combustion pass through the upper layers of fuel, together with the air, which is nearly freed from its oxygen, thus decarbonising the fuel and facilitating the formation of smoke, the fire-place we have just described always brings fresh air from above into contact with the fuel; a more perfect combustion is thus induced, and the products of combustion are carried off from below. The loss which, in ordinary fire-places with grates, is caused by the formation of cinder is also avoided, and analyses of ash, as well as the absence of smoke, prove that the combustion is perfect, and that no cold air can enter the furnace hearth.

This kind of fire-place not only produces the greatest amount of heat, but also the highest temperatures if only kiln-dried wood is employed and kept in the fire-place in such a quantity as the introduced air is capable of burning. The perfect utilisation of the fuel is effected by the smallest possible quantity of air, and a large proportion of heat, compared with the quantity of gas, is produced; these circumstances produce the very highest temperature. These fire-places are therefore better adapted for heating than for roasting furnaces, and they are employed,* for example, in Austrian and Bavarian salt-works, in porcelain furnaces, in puddling furnaces, &c.

The fuel best adapted for these fire-places is wood, as it supports itself when placed in the fire-place, thus affording always a free passage for the air. The construction of these fire-places still leaves some questions open to consideration. It will not, therefore, be unimportant to what height the shaft above the opening, *e*, is constructed, as, by this circumstance, the space of combustion is more or less raised; it is furthermore doubtful whether it is admissible to increase the vertically burning plane at the expense of its horizontal extent, &c.; but it is certain that these fire-places offer all the means required for determining the quantity of wood which shall be burnt per hour, supposing the chimney to be of fixed dimensions, as the projections, *d*, front wall, *b*, &c., may be constructed so as to be movable, and may be erected afresh after each operation.

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* TUNNER'S Jahrb., 1847. Oesterr. Ztschr., 1859, p. 259. B. u. h. Ztg., 1848, p. 226; 1854, p. 357.

Von Schwind has stated the dimensions of some of these fire-places, and the quantities of wood daily consumed in them, to be as follows:—

| | I. | II. | III. | |
|---|---|---|---|---|
| Breadth of the fire-place (length of the pieces of wood) . . . . . | 40 | 43 | 43 | inches |
| Width of the fire-place . . . . | 12 | 16 | 10 | ,, |
| Height of *f* above the projections, *d* | 11 | 11 | 11 | ,, |
| Height of the shaft above *f* . . . | 26 | 31 | 31 | ,, |
| Burning surface . . . . . . . . | 4·5 | 5·5 | 4·4 | square feet |
| Daily consumption of pine wood about | 42 | 44·94 | 25·15 | cwts. |

These fire-places are likewise constructed so as to be fit for burning turf and mineral coal.*

Von Posch† has recorded his experience with these fire-places, which he considers valuable as smoke-consuming apparatus.

## Drying the Fuel.

The effect of a fuel, in combustion, depends on the quantitative composition of the organic substance, and the construction of the fire-place, as well as on its amount of hygroscopic water, which becomes volatilised and impairs the combustibility and inflammability. The hygroscopic water renders the combustion imperfect, and gives rise to a smoky flame, causing a loss of fuel; the apparatus and substances to be heated become coated with soot, which impairs the processes of oxidation (roasting processes, &c.).

The organic substance contained in wood, for instance, on evolving 4000 units of heat, produces a temperature of 1700° C., which, however, is reduced to 1380° C. if the wood contains 40 per cent of water, and to 1120° C. if the proportion of water amounts to 82 per cent. Air-dried wood contains 20 per cent of water, and 5 per cent of carbon are required to evaporate that water and to heat the steam; the diminished value of such wood therefore amounts to 25 per cent. An amount of hygroscopic water is less disadvantageous if the production of only a certain quantity of heat is required, or if the gaseous products of combustion escape in the open air, having meanwhile a temperature below that in which the watery vapours contained in the gases condense (roasting processes). On the other hand, water is very injurious if the rapid production of high degrees of temperature is designed. Whilst in the former case it will suffice to dry the fuel in the open air, in the latter case the water must be expelled by a higher temperature (drying in kilns).

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* DINGL., cx., 93. B. u. h. Ztg., vii., 281. MUSPRATT-STOHMANN's techn. Chem., iii., 1341.

† SCHEMNITZER und LEOBENER Jahrb., von FALLER, viii. (1858), p. 112.

Only *wood* and *turf* are dried in this manner, and, in some cases only, *brown coal*. *Mineral coal* contains but little hygroscopic water, while, on the other hand, brown coal contains a great deal. Part of it may be removed by storing the brown coal for a long time under airy shelters. Drying in kilns is only advantageous where the brown coal does not disintegrate too much in the operation (lignite, for instance) and where it is intended for the production of the higher degrees of temperature, which is the case in some establishments in Austria and Bavaria.

### 1. Drying Fuel in the Open Air.

Freshly cut *wood* is divided into pieces of a suitable size, which are then piled up in regular heaps in a dry and airy place. This piling up of the pieces of wood is performed in various ways.*

The design of drying is more fully accomplished if the heaps of wood are kept under airy shelters, but this is too expensive a method if carried out on a large scale.

Wood that is hewn down in the course of the winter will contain about 40 per cent of water at the end of the following summer, and from 15 to 20 per cent even if kept for several years.

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* TUNNER's Stabeisen-und Stahlbereitung, Bd. i., p. 20. SCHEERER's Metallurgie, i., 172.

*Turf* usually contains so large a quantity of water that, before it is used, it must be kept for a long time exposed to the air, in order to expel part of the water.

As turf exists in Ireland in great abundance, covering, indeed, about one-seventh part of the island, the ordinary occurrence of this substance can be best illustrated by a reference to that country. We therefore insert the following account of its origin, abstracted from the "Bog Report" of Mr. Nimmo* :—He says, referring to cases where clay spread over gravel has produced a kind of puddle, preventing the escape of waters, of floods, or springs, and when muddy pools have thus been formed, that aquatic plants have gradually crept in from the borders of the pool towards their deep centre. Mud accumulated round their roots and stalks, and a spongy semi-fluid was thus formed, well fitted for the growth of moss, which now principally appears; *Sphagnum* began to luxuriate, this absorbing a large quantity of water, and continuing to shoot out new plants above, while the old were decaying, rotting, and compressing into a solid substance below, gradually replaced the water by a mass of vegetable matter. In this manner, the marsh might be filled up, while the central or moister portion, continuing to excite a more rapid growth of the moss, would gradually be raised above the edges, until the whole surface had attained an elevation sufficient to discharge the surface water by existing channels of drainage, and calculated by its slope to facilitate their passage, when a limit would, in some degree, be set to its further increase. Springs existing under the bog, or in its immediate vicinity, might indeed still favour its growth, though in a decreasing ratio; and here, if the water proceeding from them were so obstructed as to accumulate at its base, and to keep it in a rotten fluid state, the surface of the bog might ultimately be so raised, and its continuity below so totally destroyed, as to cause it to flow over the obstruction and flood the adjacent country. In mountain districts, the progress of the phenomenon is similar. Pools, indeed, cannot, in so many instances, be formed, the steep slopes facilitating drainage, but the clouds and mists resting on the summits and sides of the mountains amply supply their surface with moisture, which comes, too, in the most favourable form for vegetation, not in a sudden torrent, but unceasingly and gently, drop by drop. The extent of such bogs is also affected by the nature of the rock below them. On quartz they are shallow and small; on any rock yielding by its decomposition a clayey coating, they are considerable; the thickness of the bog, for example, at Knocklaid, in the county of Antrim (which is 168 feet high) being nearly 12 feet. The summit bogs of high mountains are distinguished from those of lower levels by the total absence of large trees.

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* URE's Dictionary of Arts and Mines, vol. iii., 380.

As turf includes a mass of plants in different stages of decomposition, its aspect and constitution vary very much. Near the surface it is light coloured and spongy, and the vegetable matter it contains is but little altered; deeper, it is brown, denser, and more decomposed; and, finally, at the base of the greater bogs, some of which present a depth of 40 feet, the mass of turf assumes the black colour and nearly the density of coal, to which it also approximates very much in chemical composition. The amount of ash contained in turf is also variable, and appears to increase in proportion as we descend. Thus, in the section of a bog 40 feet deep at Tanahoe, those portions near the surface contained 1½ per cent of ashes, the centre portions 3½ per cent, while the lowest 4 feet of turf contained 19 per cent of ashes. In the superficial layers it may also be remarked, that the composition is nearly the same as that of wood, the succulent material being lost, and in the lower we find the change still more complete.

Notwithstanding these extreme variations, we may yet establish the ordinary constitution of turf, with sufficient certainty for practical use.

For the purpose of drying, the following methods are employed:—

1. **Drying Turf in Open Heaps.**—The turf, immediately after being cut, is piled up in small loose heaps, which are exposed to the open air, when the result will chiefly depend on the state of the weather. The turf must remain in the open air for at least two months, and when stored it usually contains more than 30 per cent of water. This mode of drying is very simple, but by no means economical, and not fit to be carried out on a large scale. Rain causes a great loss of material, chiefly with the earthy kinds of turf.

2. **Drying Turf on Racks.**—This method is used in the Upper Hartz and at Freudenberg* in Carinthia. At the latter place, the turf, consisting of two-thirds of the brown bituminous kind, with from 5 to 8 per cent of ash, and of one-third of light, spongy turf, with from 3 to 5 per cent of ash, is cut into small pieces and formed into a heap; water is then thrown on it, and it is kneaded by being trodden upon. The mass thus prepared is beaten into trapezoidal moulds. The resulting turf bricks are 4¾ inches high, 14½ inches long at the top, and 15½ inches at the bottom, and 3¾ inches broad at the top, and 5 inches broad at the bottom. The drying is effected on racks, in small wooden houses 7½ feet high and 54 or 60 feet long, which are open at the sides. A rack 60 feet long holds about 2000 bricks, which dry in five or six weeks, and are turned only if the weather be very wet. This method of drying is also employed at Buchscheiden in Carinthia, at Kessen in Tyrol, and at Ebenau.

At the Upper Hartz, the turf is first dried in heaps, and afterwards on racks; the houses containing the racks are provided with shutters at the sides, to form a protection against the rain.

At Staltach, the drying of turf is successfully performed in solidly built houses.

The air-dried turf, however, always contains from 20 to 30 per cent of water.

3. **Drying Non-Bituminous Turf,** containing 3 or 5 per cent of ash.—The following method is employed at Buchscheiden:—The turf is cut into bricks, 10 inches square and

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* ZERRENNER's met. Gasfeuerung, Wien., 1856, p. 186. TUNNER's LEOB., Jahrb., 1857, p. 137. B. u. h. Ztg., 1857, p. 106; 1858, p. 341.

3 inches thick, which are allowed to remain on the ground for two or three days, in order to attain sufficient consistency. For drying them, the following apparatus is used:—A wooden pole 3 or 4 inches thick, contains eight or nine horizontal cross bars, 1 inch thick, and 2 feet 6 inches long. The cross bars are pointed at both ends. On each half of them, projecting from the wooden pole, four or five bricks of turf are placed, the bricks having a hole for the purpose in the centre of their square surface, which surface, therefore, stands parallel with the pole, and is thus less exposed to the rain. These apparatus are placed in rows 5 feet apart, and 180,000 of them are in use, lasting 8 or 10 years. Similar apparatus made of iron would be preferable. The drying occupies from 3 to 8 weeks, usually from 4 to 6 weeks, and may be repeated five times in a year. Bituminous turf contracts two-thirds of its volume in the process of drying, and the light non-bituminous turf one-third.

In favourable weather, a better and quicker drying is effected by this method than by any other; and it may be employed even if the weather be unsettled, as a few fine days make up for a number of wet ones. The apparatus are cheaper than drying houses, and the turf is placed on the apparatus more quickly than on the racks, and causes even less labour than the drying in open heaps.

Disadvantages always attend the keeping of the turf over winter;* the frost increases its volume, and spoils its structure; a thaw in the spring lixiviates combustible components, and a very light porous product will remain. The effect of frozen turf is very slight.

## II. Drying Fuel in Kilns and Stoves.

Although air-dried fuel, especially good turf, yields as high a temperature as is required in a puddling furnace, an artificial drying of the fuel in kilns, &c., will be necessary, if the production of still higher temperatures (those required for re-heating furnaces, for instance) is intended.

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* ZERRENNER'S met. Gasfeuerung, pp. 198, 204. Oesterr. Ztschr., 1855, p. 268.

The apparatus for this drying must answer the following conditions:—The temperature required must be produced and kept up in the cheapest possible way; the fuel must be warmed gradually for a sufficient length of time; the emitted vapours must be well carried off; the apparatus must admit of an easy charging and discharging, and it must be possible easily to extinguish an accidental ignition of the drying fuel.

The process of drying in kilns has for its object to expel the hygroscopic moisture of the fuel without causing any chemical decomposition; the temperature employed must not therefore greatly exceed the boiling point of water, nor be much below it. According to Marsilly, turf undergoes a real decomposition at a temperature of 100° C., as carbonaceous products as well as water are evolved. On drying at a temperature of from 100° to 200° C., a product of greater heating power is obtained, but, on the other hand, a loss of heating power also takes place, and this power does not increase in just proportion to the loss in weight.

The artificial drying is usually carried on only so far as to leave 10 per cent of water in the fuel; it is continued further when the fuel is intended for metallurgical processes; care must then be taken to employ the turf at once after it is dried, as otherwise it will again absorb moisture.

The differently constructed apparatus used for artificial drying,* may be classified as follows:—

1. The fuel is dried in a chamber, by means of heat radiated from stoves or tubes (drying by radiation).
2. The fuel is dried by means of hot products of combustion, which are produced by a special firing, or obtained otherwise (drying by smoke).
3. The fuel is dried by means of air, which is artificially heated in some way (drying by hot air).

These systems of drying are sometimes employed in combination.

The drying of the fuel takes place more quickly and uniformly if the watery vapours evolved are rapidly carried off, if the temperature in the drying chamber is uniform, and if a great quantity of hot gases pass through the chamber. For these reasons, the second and third methods of drying exert a greater effect than the first, which produces a higher temperature at the top of the chamber than on the floor, and the heat at the upper part is so great that it induces a partial decomposition of the fuel. The openings with which the upper part of the drying chamber is provided for the emission of the watery vapours, must usually be closed towards the end of the process, in order to prevent the dried wood from igniting. Le Play advocates the first method of drying; he considers it the most perfect, since the drying takes place less by means of the quickly expelled air, than by the overheated steam that is produced. He states that six parts of dried wood are obtained by burning one part of wood.

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* EULER, in der Zeitschr. des ver. deutsch. Ingen., Bd. 3, Hft. 5 and 6.

The apparatus of the third class are the least dangerous as regards the ignition of the drying fuel; the second system of drying is usually cheaper and more effective, and it is also perfectly safe in point of ignition, if the hot products of combustion are previously passed through a chamber for collecting the sparks, as is done at Lesjöfors in Sweden.

A chamber of this kind is provided with an aperture for admitting the air; this aperture lies above the opening for the admission of the hot gases, and may be more or less closed by means of a sliding door, thus serving to moderate the temperature of the gases before they are emitted into the drying chamber. The sparks, also, are collected in this chamber. The chamber is not required if the gases are previously cooled by being used for another purpose (for heating boilers, for instance) so as to allow of their immediate admission into the drying chamber.

In this method the temperature is more perfectly utilised than in the first and third methods, since all the products of combustion freely pass through the drying chamber. When a large quantity of fuel is proposed to be dried by the first and third methods, a very high temperature must be employed; there is then, however, great danger of igniting the fuel.

A most advantageous drying apparatus, employed at

Lesjöfors in Sweden, is described by Tunner.* It is so constructed that the hot gases, instead of entering at the floor and passing out through the roof, as is the case in most apparatus, are conducted down from above by means of an exhausting fan, thus causing a better and more uniform drying.

Von Schwindt† considers that, in drying, the following conditions are required for a perfect utilisation of the heat:—A division of the material, and the formation of large surfaces; the production of a warm dry current of air; a movement of the material against the current of air; an emission of the air used for drying before the watery vapour contained in it has been condensed. In order to fulfil these conditions, the apparatus ought to consist of a channel about 24 feet long, 3 feet wide, and from 4 to 6 feet high, in which an endless chain, carrying the fuel to be dried, is moved against a current of hot air. Such an apparatus occupies much space, and is similar to those employed in Ireland and also at Lesjöfors.

## Examples of Drying Apparatus.

A. Drying chambers heated by radiated heat, which is produced in stoves or tubes (drying by radiation).

The stoves are either provided with a special fire-place with an ordinary or step grate, from which the products of combustion are conducted into the drying chamber by means of tubes, or the waste gases of other furnaces are employed.

1. **Apparatus Provided with Special Fire-place for Drying Wood.**—At Neuberg‡ in Styria, the apparatus consists of a drying chamber 36 feet long, 16 feet wide, and 13¼ feet high. This chamber has an arched roof, and is provided on one side with a fire-place having a plane grate, and, on the opposite side, with a chimney 24 feet high, and 2 feet square; the fire-place and chimney are connected by

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* Tunner, das Eisenhüttenwesen in Schweden: Freiberg, 1858, p. 60. Leob., Jahrb., 1860, p. 108.

† B. u. h. Jahrb. von Leoben und Przibram, Jahrg., 1857, Bd. vii., p. 1.

‡ Tunner's Stabeisen-und Stahlbereitung, Bd. i., p. 22. Stamm, neueste Erfindungen, No. 14, de 1859.

two tubes, 12 inches wide, which lie inside the chamber 2¼ feet from the bottom, and which convey the hot products of combustion into the chimney. The roof contains some openings for the escape of the watery vapours. The wood to be dried is loosely piled up in the chamber, in such a manner as to leave an open space, about 4 feet high and 5 feet broad round the tubes. After three days' firing the wood will be dry, and in this time about 100 cubic feet of green wood, and 25 cwts. of inferior brown coal will have been consumed. This apparatus is only advantageous where a very inferior fuel, rich in ash, and requiring a strong draught, is used.

Le Play describes a similar apparatus, provided with a step grate, in which cinders are used as fuel.

**2. Apparatus for Drying Wood with the Application of the Waste Gases from Puddling Furnaces.**—A very simple apparatus of this kind is used at Carlshütte; it is suitably provided with valves, which regulate the draught of the puddling and re-heating furnaces. The part of the tube for receiving the gases is connected with the flues of the furnaces; it is made of cast-iron coated with loam, while the other half of the tube, which conducts the gases into the chimney, is made of sheet-iron.

The apparatus used in Villotte,* near Chatillon, on the Seine, is represented in Figs. 50, 51, and 52. The walled-up chambers, A, are divided into fourteen compartments by the partition walls, *a*. The arched roofs of the chambers are kept together by means of the grappling iron, *b*, and the wedges, *c*. The iron bars, *d*, form the linings at B, of the doors, made of strong iron plate. Each chamber contains two iron bars, *e*, placed on their edges, which serve as rails; at the back, they are fixed in the walling, and, at other places, they are fastened on wooden sleepers, *f*, by means of wedges. Each compartment receives one carriage, C, resting upon cast-iron wheels, and weighing 47 kilos. The partition walls, *a*, prevent the other carriages from igniting if one should accidentally take fire. The gases are produced from kiln-dried wood; after having passed the hearth of the puddling furnace, that for the preparatory heating of the

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* CAILLETET in Bulletin de la Société de l'industrie Minérale, i., 473. DINGL., Bd. 143, p. 414.

FIG 50.

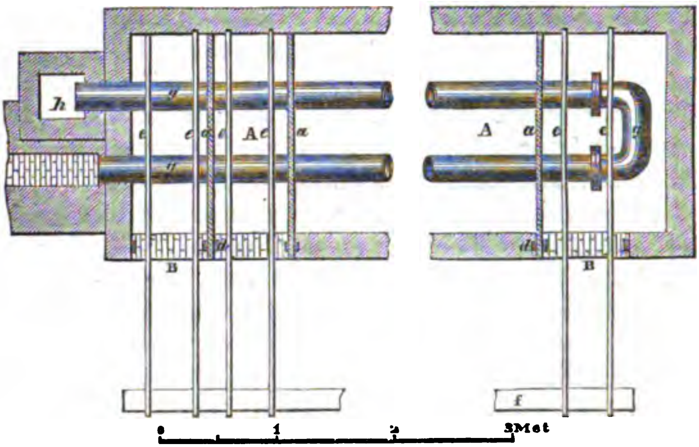
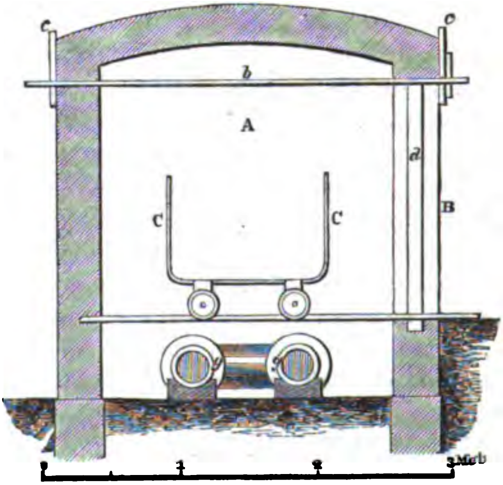
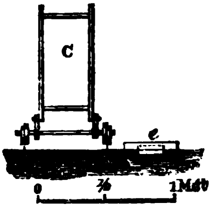


FIG. 51.



pig-iron, and the space for heating the blast, they enter the tube, *g*, circulate through it, and escape into the chimney, *h*, which is 12 metres high. The temperature in the drying chambers is raised up to 120° or 130° C., from the time of charging the puddling furnace until the balls of puddled iron are removed.

FIG. 52.



The wood (oak and beech, with a little lime wood) to be dried, is in pieces, 0·66 metre long, and contains about 30 per cent of moisture; in summer it is kept in the drying chambers for 28 or 30 hours, and, in winter, for 48 hours. The dried wood has a yellowish colour, is contracted, breaks easily, and contains about 4 per cent of water, having at the same time lost 27 per cent of its weight. Dried wood is very pyrophoric. If a carriage in the chamber catches fire it is withdrawn, and the fire extinguished with water.

Apparatus of this construction for drying turf were employed at Königsbrunn and Wunsiedel,* but they did not give satisfactory results, as the whole mass could not be uniformly warmed, and the necessary removal of air and the escape of the watery vapour took place too slowly. When the watery vapours are made to escape through openings in the roof, they are retained too long in the building, whilst the heat rapidly escapes.

### B. Drying Chambers Heated by Hot Products of Combustion which are conducted into the Chambers.

The drying chambers have either a special firing, which is the case in Buchscheiden, Mariazell, Lippitzbach, Frantschach, Rothehütte, and Ireland, or the products of combustion of other firings are employed. The hot gases are conducted either in a horizontal direction (Ireland), or upwards from below (Buchscheiden, Lippitzbach, Frantschach, Rothehütte, &c.,) or from above downwards (newer mode at Lesjöfors in Sweden, Mariazell, Maximilianshütte, near Regensburg, &c.)

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* VOGEL, der Torf. München, 1859, p. 56.

The direct application of the products of combustion has two disadvantages. These products or gases are usually obtained from inferior fuel that is not perfectly dry; they, therefore, contain watery vapour, which condenses in those parts of the drying chamber that are raised to a less high temperature. Besides, owing to their high temperature, the gases induce a vehement evaporation of water on the surface of the pieces of turf before the heat has penetrated the interior mass, in consequence of which the pieces of turf become rent. For this reason wet brown coal cannot advantageously be dried by this system. In this method there is also a danger of igniting the fuel to be dried if the gases are not conducted through a chamber for collecting the sparks.

Owing to the high temperature of the gases of combustion, these apparatus heated with direct firing work quickly and yield a very dry turf; but, on the other hand, they require much fuel, as a great deal of the heat escapes without being used. The application of mechanical contrivances, fans, &c., is not only expensive in the first plant, but their use necessitates a further consumption of fuel. These contrivances are, therefore, only advantageous in places where cheap fuel abounds, and where the production of a very dry turf is intended.

### 1. Drying Apparatus with a Special Fire-place.

The turf from Ireland,* when cut in the most favourable weather, appears dry to the touch, but in reality contains water amounting to one-fourth or one-third of its weight. This turf is dried in a horizontal channel about 100 feet long, 8 feet high, and 8 feet broad, by means of hot products of combustion, which are generated from waste turf in a fire-place situated at the end of one of the long sides of the channel. The wet turf is placed on light carriages having a grate-like bottom plate, and which run on rails. These carriages are then moved into a channel at intervals of from ten to twelve hours, in such a manner that the wet turf enters one side of the channel, and is gradually moved towards the other end, whence it will at last come out in a perfectly dried state. As soon as one carriage with dried turf is withdrawn, another laden with wet turf will be pushed into the channel at the other end. Smoke and moist air escape through two small chimneys placed at the end of the channel. The lower openings of these chimneys are on a level with the bottom of the channel, so that the coldest, densest, and moistest air may be sucked away from the channel first. To prevent the dry turf from being ignited by sparks which are carried along, the hot products of combustion are made to pass through a web of iron wire fixed into iron frames before they enter the channel.

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* Mittheilungen des Hannov. Gewerbe-Vereins, 1846, p. 71.

An apparatus of the before-stated dimensions, twenty carriages included, costs about £215, and dries 10,000 cubic feet of turf in six or seven days. About 700 cubic feet of small turf and other rubbish and waste are consumed for producing the heat.

At Buchscheiden, near Klagenfurt, the air-dried turf (page 300), as well as wood, is dried in the eight chambers of an apparatus represented in Figs. 53, 54, 55, and 56. A is the space for the reception of the turf; B, the openings for charging; *g* is a wooden grate; C is the space below the grate; D is the fire-channel, having the grate, E, at one end, and the openings, O, at the other. The fire-channel leads into the space, F; *p* are openings in the back wall of the chamber, A; *r* are openings for the escape of the moist gases; H are openings for discharging the apparatus; they are closed with wooden doors; T are openings leading to the spaces F and C.

The operation of drying is carried on in the following manner:—In the space, A, pyramids about 6 feet high are formed of pieces of wood, and inside and around them turf

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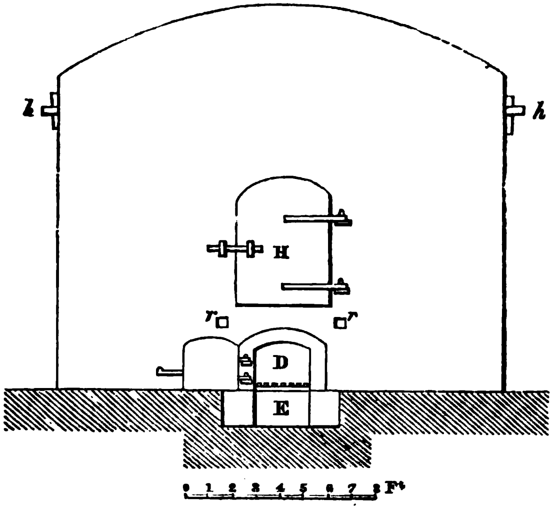
[*] ZERRENNER's Gasfeuerung, p. 175. B. u. h. Ztg., 1857, pp. 120, 130. TUNNER's LEOB. Jahrb., 1857, p. 141.

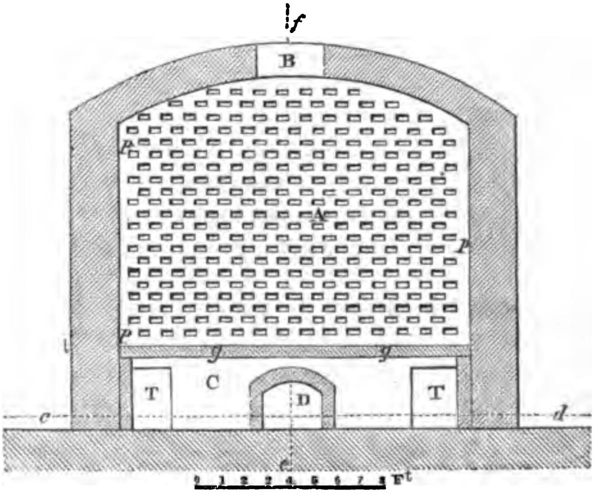
is thrown. The interstices thus formed, by allowing a free passage to the hot gases, facilitate the drying, and more than

FIG. 53.



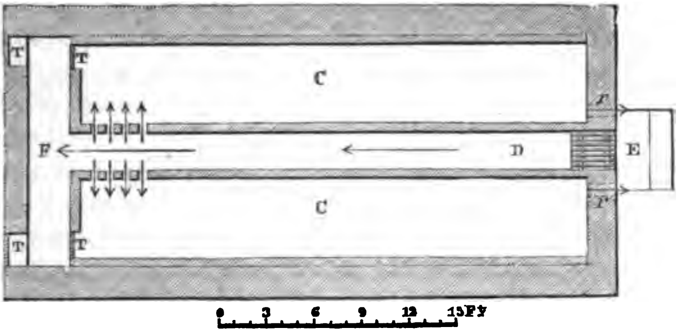
recompense for the time and labour expended on the formation of the pyramids. After having charged the turf, the

FIG. 54.



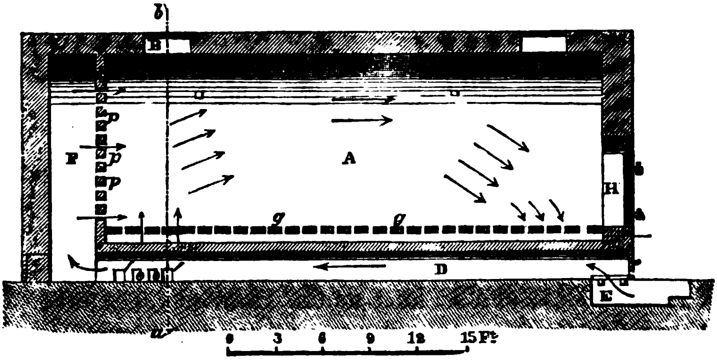
small particles falling through the grate are carefully removed, the walls of space F are cleaned from soot, the openings, K, for discharging, and those, T, for cleaning are firmly

FIG. 55.



closed, a fire is kindled on the grate, E, and as soon as draught is induced, the openings, B, for charging, are also closed with cast-iron plates.

FIG. 56.



The hot gases produced on the grate, E, pass in admixture with atmospheric air through the channel, D, partly into the space, C, and partly into F, hence into the chamber, A, through the interstices of the grate and the openings, *p*, where they permeate the turf, absorbing moisture, and escape through the openings, *r*. The temperature in the chambers amounts to from 75° to 87° C. The fire is kept up with turf, waste of wood, and inferior brown coal, and when bricks of turf are employed, the consumption amounts to 8 per cent of the drying turf. The drying occupies from three to five days, the cooling from one and a half to three days, when the flues must be hermetically closed until the fire is extinguished. The dried turf is immediately given to the puddling and re-heating furnaces. The wood employed for erecting the pyramids is used again in the following operation. If the spaces F and C are not perfectly freed from small turf, the turf will be liable to catch fire. With regard to time and the degree of dryness, these apparatus give very satisfactory results; but, on the other hand, they consume a great quantity of fuel, and do not admit of a large production.

A similar apparatus provided with a step-grate is in operation at Rothehütte in the Upper Hartz.

In the apparatus used at Frantschach,* the hot gases generated on the grate pass first into a long channel erected on the sole of the chamber, and then through the open end of that channel into the chamber. The cooled gases, together with the watery vapours, escape through openings in the side walls. The fire is kept up for five days, and 10 per cent of green wood of the most inferior quality is consumed. The construction of this furnace is less judicious than that of the preceding apparatus.

The chambers used at Lippitzbach† in Carinthia are 8·55 metres long, 5·52 metres broad, and 4·37 metres high, measured at the vertex of the arched roof. The space above the grate is capable of containing 130 cubic metres of wood. Below the grate two walled channels 0·47 metre broad, 0·68 metre high, and as long as the chambers, are erected, on the sole of which, to a length of about 2 metres, wood chips and other waste wood are kept burning. The hot gases thus generated pass through holes with which the roofs of the channels are provided, then through the grate, and permeate the wood in the chamber with a temperature of about 180° C. The gases become cooled down to from 30° to 90° C., and escape from the apparatus through six openings of a total section of 14 square decimetres. The openings are placed on a level with the hearth.

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* TUNNER, Stabeisen-und Stahlbereitung, i., 22 (with drawing).

† B. u. h. Ztg., 1857, p. 119.

In summer the fire is kept up for at least 2½ days, and in winter time for six days, that is, until no more watery vapours are perceptible in the escaping gases. On an average, 0·33 cubic foot of wood are consumed per cubic foot of dried wood.

### 2. Drying Apparatus Heated by the Waste Gases of other Furnaces.

The hot gases pass through the fuel to be dried, either upwards from below or the contrary way; but they must previously have passed through a chamber for collecting the sparks in case the gases have not been already cooled by being used for other purposes.

According to the older method used at Lesjöfors* in Sweden, the waste gases resulting from three Lancashire finery hearths are used for a preparatory heating of the pig-iron and for heating the blast. They then enter into a common channel, and hence into two channels lying side by side, for the purpose of heating two boilers. The gases afterwards re-unite into a common channel, which conducts them into the drying chamber. This chamber consists of a channel 66 feet long, 6½ feet broad, and 8½ feet high, having a railway on its sole. The first 12 feet of the channel are in horizontal position, the remaining length has an ascent of 16 feet. The carriages are simply iron frames resting upon four wheels, upon which the pieces of wood intended for drying are piled; the railway inside the channel has room for seven carriages of this kind. The carriages are joined to an endless chain, and may be moved at will by means of a windlass. In proportion as carriages with dried wood are withdrawn from the chamber, others carrying fresh wood are again introduced. The gases escape through an opening at the bottom of the chamber, when they still have a temperature of from 60° to 100° C. Each carriage is kept in the chamber for about 30 hours.

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* TUNNER's Stabeisen- und Stahlbereitung, i.. 23. TUNNER, das Eisenhüttenwesen in Schweden, p. 58.

The following is the newer method employed at Lesjöfors :*—The drying chamber is built of bricks made of blast furnace cinder, and well fastened with grappling irons; its sole or bottom is made of lattice, and constructed in the shape of angular roofs, that is, like four roofs lying side by side. This bottom is provided with a number of valves, which are opened for the purpose of withdrawing the dried turf into cars which are placed below; the chamber is filled with 2200 or 2500 cubic feet of turf. The waste gases of a Lancashire finery hearth are then conducted into the chamber through an opening below the roof by means of a channel, which may be closed with a sliding valve. Before entering the drying chamber, the gases are made to pass through another for collecting the sparks. The channel conducting the gases into the chamber is closed at the top with an iron plate and sand, and provided with a thermometer, which usually indicates a temperature of from 100° to 140° C. The channel for withdrawing the gases is at the bottom of the chamber, and is covered with iron lattice as far as it is inside the chamber; outside of the furnace it is about 60 feet long and arched over with brick-work. At the end of it an exhauster is placed, which is 60 inches in diameter, 16 inches in breadth, and makes 300 revolutions per minute, and by means of this exhauster the hot gases impregnated with moisture are withdrawn. The operation of drying takes four, or at the most five, days, and that of cooling about half a day.

Based upon the same principle, though of somewhat different construction, are the apparatus at Lesjöfors, connected with re-heating furnaces; they are represented in Figs. 57 and 58. The eight chambers, *a*, are provided with the lattice grate, *b*, and with the openings, *c*, through which the turf is charged and withdrawn. The waste gases of the re-heating furnaces (after having passed through a chamber for collecting the sparks, if such is required), pass through the channel, *d*, into the vertical channel, *e*, and hence into the horizontal channel, *f*. This channel is connected with each chamber by means of the flue openings, *g*, through which the gases are forced by means of an exhauster, which is placed at the end of the channel, *h*; the exhauster makes 400 revolutions per minute. The channel, *h*, is provided with the two valves, *i*, which may be regulated by means of two connecting rods.

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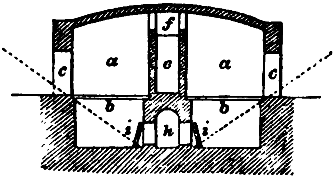
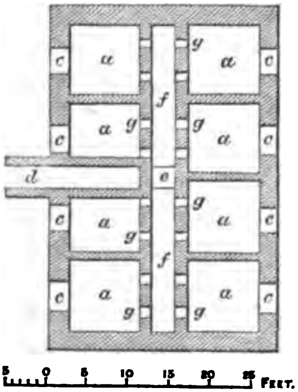
* TUNNER, Eisenhüttenwesen in Schweden, pp. 24, 61.

FIG. 57.



This Swedish method of drying is a most judicious one; the turf is brought into contact with a large quantity of warm, dry gases, and the moisture is carried off from below.

FIG. 58.



At Maximilianshütte,* near Regensburg, brown coal is dried by products of combustion generated in a special fire-place. These hot gases, in mixture with air, are carried downwards through the brown coal by means of a fan.

## C. Drying Apparatus Heated with Hot Air.

These apparatus are advantageous only where there is a possibility of heating the air by means of waste gases of other fire-places, and where the motive power for a fan is at disposal, or where the blast engine employed has blast to spare for the drying apparatus.

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* LEOBENER, &c., B. u. h. Jahrb., 1858, Bd. viii., p. 121.

The apparatus used at Freudenberg,* in Carinthia, has a chamber capable of containing from 3500 to 4000 cubic feet of turf; the arched roof of the chamber is provided with the openings for charging, and a railway runs above these openings. The bottom of the chamber is constructed of wooden lattice, having interstices 1 inch wide. The space below the lattice bottom contains two arched channels, the side walls of which are provided with ten openings, 6 inches wide and 12 inches high; these channels receive from 350 to 400 cubic feet of air per minute, which is heated up to 130° to 150° C. The space below the lattice bottom contains also the opening for the escape of the moist and cool gases.

The blast is heated with the waste gases of puddling furnaces, and introduced into the warming apparatus at a low pressure. The turf will be dry in about three or five days, when the blast is shut off by means of a valve, and the apparatus is allowed to cool gradually for three or four days.

When too hot a blast is employed, or when care is not taken to remove all the waste fuel from below the lattice bottom, the turf is liable to ignite. If this is the case, the fire cannot be extinguished by shutting off the air, as, in spite of this precaution, turf will continue to smoulder for weeks. It can only be extinguished by introducing water. On the other hand, if a chamber filled with wood takes fire, it may be extinguished in a few days by hermetically closing all the openings of the chamber.

If hot blast is not at disposal, openings are sometimes made in the front wall of the channels, below the lattice bottom, the blast pipes are removed, and a faint fire is kept up before the openings.

Drying with hot air is said to be more advantageous for turf than for wood; but, on the other hand, much time has to be expended on the charging and discharging of the chambers.

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* TUNNER, Stabeisen- und Stahlbereitung, i., 26. B. u. h. Ztg., 1857, p. 107. ZERRENNER'S Gasfeuerung, p. 190.

An apparatus for drying wood, used at *Zorge* in the Hartz, has three compartments, each 40 feet long, 5 feet 5 inches high, and 7 feet 4 inches broad. Each of these compartments or chambers is subdivided into two parts by means of a movable sliding door, which is balanced by a counterpoise. After having placed three carriages laden with wood in each of the divided compartments, that is, eighteen carriages in all, holding about 2000 cubic feet of wood, the iron folding doors before the charging openings are closed, and the joints filled up with loam.

The hot air is introduced into the first compartment through an oval pipe, measuring 16 inches one way and 9 inches the other, provided with holes ⅛ or ¼ of an inch in diameter; the wood on the three carriages of this compartment is thus dried, and the hot air passes through two openings, 8 inches square, with which the lower part of the sliding door is provided, into the second compartment. The air pipe is placed below the sole of the drying chamber into a channel open at the top, the side walls of which carry rails for the carriages; 1200 cubic feet of blast are introduced per minute. The blast, on entering at the bottom of the first compartment, has a temperature of 152° to 182° C., which, however, is already decreased to 63° C. when the blast arrives at the roof of the first compartment, and to 37° C. when it passes into the second. The moist gases in the three last compartments escape through openings 6 inches in diameter, which are made for the purpose in the roofs. The wood has been previously dried in the open air, and is in pieces 3 feet long, and about 14 square inches in section; it is said to lose 16 per cent of water in 7 days, and 8 per cent more when kept 10 days longer in the apparatus.

At Kessen* in Tyrol, and at Brezowa† in Hungary, turf and wood are also dried by means of hot blast.

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* ZERRENNER, Gasfeuerung, p. 198.

† Ibid., p. 230.

## D. Drying Apparatus, Applying Radiated Heat and Hot Air in Combination.

**Weber's Method.**—The apparatus erected by Weber at Haspelmoor,* in Bavaria, contained a drying chamber 13 feet high, and of a capacity of 70,000 cubic feet. On the floor of the chamber, or partly below it, four channels run through the whole length of the building; they are constructed partly of stone and partly of iron, and each is provided with a fire-place, and is also surrounded by a second channel, which receives the air through two openings at the side of the fire-place, and again emits the hot air into the drying chambers through six openings, which may be closed at will. The four double channels, therefore, contain twenty-four openings for the emission of hot air, and they are so constructed that the interior space may be uniformly warmed and filled with dry air. Three lines of rails are laid down in the chamber, making room for thirty carriages of such construction, that the half-dried turf may be piled up upon them 10 feet high, without being compressed too much by its own weight. Between the railway lines above the fire channels wooden scaffolds are erected, allowing the turf to be heaped up in a similar manner as on the carriages, all the way up to the roof. Openings for emitting the cold and moist gases are provided on the lower part of the four side walls; their draught is assisted by small chimneys made of zinc, which project some feet above the roof of the building. The chamber contains about 200,000 pieces of turf.

This method of drying is a perfectly judicious one, possessing none of the disadvantages which attend that by which the hot products of combustion are applied direct, and it yields a perfectly dry material without disintegrating it. This method has, however, been abandoned again, as it was expected that still better results would be obtained by pressing dried turf dust after Exter's system.

Euler's drying apparatus,† which is in use at Trippstadt in Bavaria, consists of a channel 53·18 metres long, 3 metres broad, and 2·5 metres high, and of a capacity of 397½ cubic metres. At the bottom of the chamber two railways are constructed, below which two smoke channels, each 0·396 square metre in section, are conducted nearly the whole length of the chamber, when they unite, leading into an iron chimney 12·16 metres high. By the introduction of steam, draught may be induced in the channels, in which the waste gases of a double puddling furnace and a re-heating furnace are collected after they have heated a boiler in which the steam necessary for the working of a fan is produced.

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* Vogel, der Torf. München, 1859, p. 64.

† Zeitschr., des Ver. deutsch. Ingenieure, Bd. iii., Heft. 5 and 6. Berggeist, No. 77, de 1859.

Below these smoke or gas channels, other channels are situated, into which atmospheric air is admitted; the air is thus warmed, and enters the interior of the chamber through openings in a partition wall, which runs the whole length of the chamber, and serves as a support for the middle rails. Hot blast (1000 cubic feet of 100° C. per minute) may also be conducted through the special pipe into the chamber. The rails in the chamber carry fifty carriages, with a total burden of about 7200 cubic feet of fuel. The ends of the chamber are closed partly with wooden doors, and partly with iron sliding doors. The rails, at both ends, have an inclination of 2½ in a hundred, and in the middle, at a length of 32 feet, an inclination of 3½ in a hundred.

## THE ASSAY OF FUEL.

The great influence which fuel exerts in all metallurgical operations will justify our adding the following additional remarks to chapter v. of the third edition of Mitchell's "Assaying:"*—

In the assay of fuel, the chief object is to determine the hygroscopic water, the behaviour on combustion, the amount of carbon to be obtained in the carbonisation process, the ash contained in the fuel, and the heating power of the fuel. Frequently, also, the external appearance of the fuel (its porosity or compactness, its fracture, the size and shape of the pieces, their friability, intermixed layers of earthy substances, &c.), enables the applicability of a fuel to one or the other purpose to be determined. The friability or cohesion of different kinds of fuel has been determined by Playfair, De la Beche, and Schrötter.

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* Third Edition, edited by WILLIAM CROOKES, F.R.S., &c.: London, Longmans, 1868. BAER, Untersuchungen verschiedener Brennmaterialien in Liebig's Jahrsb., 1847-8, p. 1112; 1850, p. 688; 1851, p. 733. TUNNER'S Stabeisen- und Stahlbereitung: Freiberg, 1858, Bd. i., p. 38. STEIN, Chem. und Chem. Techn. Untersuch. der Steinkohlen Sachsens: Leipzig, 1857.

Injurious substances of the fuel, such as sulphur, sulphuric acid and phosphoric acid, as well as the components of the ash, can only be determined by chemical analysis.

Frequently the blowpipe may be advantageously employed in the assay of fuel.

For the purpose of observing the behaviour of fuel on combustion, it is heated in a muffle with the admission of atmospheric air; in this operation care must be taken to observe whether the fuel ignites easily or with difficulty, whether it cakes or disintegrates, whether it burns with a long or short flame, whether the flame be intense, smoky, more or less bright, steady or vacillating, or whether the fuel only glows; whether a smell is generated, whether the resulting coke continues to burn for a long time or easily goes out, whether the remaining ash is easily fusible or not, &c.

## Determination of the Heating Power.

The value of a fuel for any purpose depends chiefly on the price and the quantity required for that purpose. The quantity needed depends on the heating power possessed by a certain weight of fuel (its *absolute* heating power) or that possessed by a certain volume (its *specific* heating power).

1. **Absolute Heating Power.**—Several methods are applied for the determination of this power.

*a.* **Rumford's Method,**[*] which is also employed by Peelet and others, determines that quantity in weight of water at 0° C., which one part in weight of different kinds of fuel, in perfect combustion, will heat up to 100° C. The following results are obtained:—

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[*] RUMFORD, über die Wärme: Berlin, 1805. ERDM., Journ. f. ök. Chem., ii., 339.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | part of | Hydrogen | raises | 236 | parts Water | from 0° | to 100° C. |
| 1 | „ | Carbon | „ | 78 | „ | „ | „ |
| 1 | „ | Charcoal | „ | 75 | „ | „ | „ |
| 1 | „ | Good Mineral Coal | | 60 | „ | „ | „ |
| 1 | „ | Dry Wood | | 36 | „ | „ | „ |
| 1 | „ | Turf | | 25—30 | „ | „ | „ |

In order to ascertain how many parts by weight of water may be raised 1° C., by a certain quantity of different kinds of fuel, the numbers stated above require to be simply multiplied by 100; it then follows that—

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | part of | Hydrogen | will heat | 23600 | parts of Water | 1° C. |
| 1 | „ | Carbon | „ | 7800 | „ | „ |
| 1 | „ | Charcoal | „ | 7500 | „ | „ |
| 1 | „ | Good Mineral Coal | „ | 6000 | „ | „ |
| 1 | „ | Dry Wood | „ | 3600 | „ | „ |
| 1 | „ | Turf | „ | 2500—3000 | „ | „ |

These ratios or units represent, therefore, the relative quantities of heat which are required to raise the temperature of one part by weight of water, usually 1 lb., 1° C.

The French units are twice as large as the German, as they represent the quantity of heat required for raising 1 kilo. of water 1°.

These figures are sometimes simplified by accepting the carbon as unit, and dividing them by 7800, when the following figures will result:—

| | |
|---|---|
| Hydrogen | 3·03 |
| Carbon | 1·00 |
| Charcoal | 0·96 |
| Good Mineral Coal | 0·77 |
| Dry Wood | 0·46 |
| Turf | 0·33—0·38 |

The absolute heating power of hydrogen is, therefore, about three times as large as that of carbon, and, consequently, the more hydrogen a fuel contains the more heat it will yield.

These caloric units have since been differently stated by various investigators. Those for carbon and hydrogen, which are the only heat-producing components of fuel, are probably the following, supposing the carbon to be burnt to carbonic acid, and the hydrogen to water:—

| | Despretz. | Grassi. | Dulong. | Favre and Silbermann. |
|---|---|---|---|---|
| For Carbon . | 7815 | 7714 | — | 8086 |
| For Hydrogen | 23640 | 34666 | 34800 | 34188 |

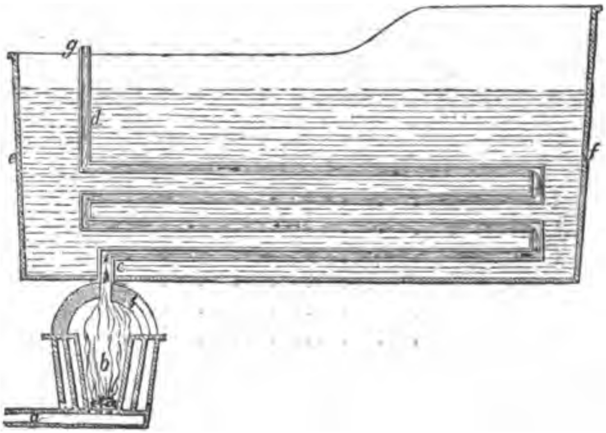
If we consider the figures of Favre and Silbermann to be correct, the units of carbon and hydrogen will stand in the proportion of 1 to 4·2.

Later investigations concerning the absolute heating power of carbonic oxide gas, have given various results. Dalton ascertained it to be 1857; Dulong, 2466; Favre and Silbermann, 2403; Grassi, 1876. The absolute heating power is, therefore, either 2403—2466 or 1857—1876.

These figures concerning $C_2H_4$ are, according to Dalton, Dulong, Favre and Silbermann, and Grassi, 6375, 13223, 13158, and 10145 respectively; and those concerning $C_4H_4$, 6600, 12172, 11900 and 8557 respectively. On burning carbon to carbonic oxide gas, Favre and Silbermann obtained the number 2480.

The calorimeter,* represented in Fig. 59, is founded on the same principle as that of Count Rumford, but with certain improvements.

Fig. 59.



It consists of a large copper bath, *e*, *f*, capable of holding 100 gallons of water. It is traversed four times, backwards and forwards, in four different levels, by a zigzag horizontal flue or flat pipe, *d, e*, 9 inches broad and 1 deep, ending below in a round pipe at *c*, which passes through the bottom of the copper bath, *e, f*, and there receives the top of a small black lead furnace, *b*. The inner crucible contains the fuel. It is surrounded, at the distance of 1 inch, by a second crucible, which is enclosed at the same time by the sides of the outer furnace; the stratum of enclosed air between the crucibles serving to prevent the heat from being dissipated into the atmosphere round the body of the furnace. A pipe, *a*, from a pair of double cylinder bellows, enters the ash pit of the furnace at one side, and supplies a steady, but gentle blast, to carry on the combustion, kindled at first by ½ an ounce of red-hot charcoal. So complete is the heat which is disengaged by the burning fuel, absorbed by the water in the bath, that the air discharged at the top orifice, *g*, has usually the same temperature as the atmosphere.

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* Ure's Dictionary of Arts and Mines, vol. ii., p. 407.

The vessel is made of copper, weighing 2 lbs. per square foot; it is 5½ feet long, 1½ wide, 2 deep, with a bottom 5½ feet long, and 1¾ broad, upon an average. Including the zigzag tin plate flue, and a rim of wrought-iron, it weighs altogether 85 lbs. Since the specific heat of copper is to that of water as 94 to 1000, the specific heat of the vessel is equal to that of 8 lbs. of water, for which, therefore, the proper correction is made by leaving 8 lbs. of water out of the 600 or 1000 lbs. used in each experiment.

In the experiments made with former calorimeters of this kind, the combustion was maintained by the current or draught of a chimney, open at the bottom, which carried off, at the top orifice of the flue, a variable quantity of heat, very difficult to estimate.

When the object is to determine the latent heat of steam or other vapours, they may be introduced through a tube into the top orifice, *g*, the latent heat being deduced from the elevation of temperature in the water of the bath, and the volume of vapour expended from the quantity of liquid discharged into a measure glass from the bottom outlet, *c*. In this case, the furnace is, of course, removed.

The heating power of the fuel is measured by the number of degrees of temperature which 600 or 1000 lbs. of water in the bath are raised by the combustion of 1 lb. of it, the copper substance of the vessel being taken into account.

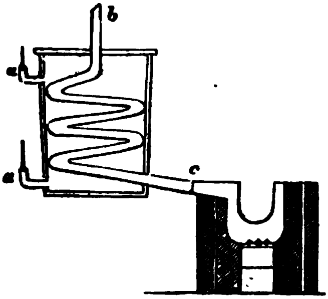
It must be borne in mind that a coal which gives off much unburnt carburetted hydrogen gas does not afford so much heat, since, in the production of the gas, a great deal of heat is carried off in the latent state.

*b.* The first, though probably not the most accurate, apparatus for measuring the quantity of heat transferable from a hotter to a colder body, was the calorimeter of Lavoisier and Laplace. It consisted of three concentric cylinders of tin plate, placed at certain distances asunder; the two outer intermediate spaces being filled with ice, while the innermost cylinder received the hot body, the subject of experiment. The quantity of water discharged from the middle space by the melting of the ice in it, served to measure the quantity of heat given out by the body in the central cylinder. A simpler and better instrument on this principle would be a hollow cylinder of ice of proper thickness, into whose interior the hot body would be introduced, and which would indicate, by the quantity of water found melted within it, the quantity of heat absorbed by the ice. In this case, the errors occasioned by the retention of water among the fragments of ice packed into the cylindric cell of the tin calorimeter, would be avoided. One pound of water at 172° Fahr. introduced into such a cylinder as the one described above, will melt exactly 1 lb. of ice, and 1 lb. of oil heated to 172° Fahr. will melt ½ lb.

*The method of refrigeration* contrived at first by Meyer, has more recently been brought to great perfection by Dulong and Petit. It rests on the principle that two surfaces of equal size and radiating force, lose, in the same period of time, an uniform quantity of heat, when they are at the same temperature. Suppose, for example, that a vessel of polished silver, of small size, and very thin in the metal, is successively filled with different pulverised substances, and allowed to cool from the same elevation of temperature, the quantities of heat lost in the first instant of cooling will always be equal to each other; and if one of these substances cools in just half the time taken by another, we may conclude that its capacity for heat is one-half, when its weight is the same, since, by losing the same quantity of heat, it sinks in temperature double the number of degrees.

*The Method of Mixtures.*—In this method two bodies are always employed—a hot body, which becomes cool, and a cold one, which becomes hot—in such a manner that all the caloric which goes out of the former is expended in heating the latter. Suppose, for instance, that we pour a pound of quicksilver at 212° Fahr. into a pound of water at 32°, the quicksilver will cool and the water will heat, till the mixture, by stirring, acquires a common temperature. If this temperature were 122°, the water and mercury would have equal capacities, since the same quantity of heat would produce, in an equal mass of these two substances, equal changes of temperature, viz., an elevation of 90° in the water, and a depression of 90° in the mercury. But, in reality, the mixture is found to have a temperature of only 37½°, showing that, while the mercury loses 174½°, the water gains only 5½°, two numbers in the ratio of about 32 to 1, whence it is concluded that the capacity of mercury is 1-32nd of that of water. Allowance must be made for the influence of the vessel, and for the heat dissipated during the time of the experiment.

FIG. 60.



*c.* In order to ascertain the relative heating powers of different kinds of fuel, the apparatus represented in Fig. 60 may also be used. The little furnace is covered at the top and transmits its burnt air by *c*, through a spiral tube immersed in a cistern of water, having a thermometer inserted near its top, and another near its bottom, into little side orifices, *a*, *a*, while the effluent air escapes from the upright end of the tube, *b*. A thermometer bulb may also be placed here. The average of the two thermometers gives the mean temperature of the water. As the water evaporates from the cistern, it is supplied from a vessel placed alongside of it. The experiment should be begun when the furnace has acquired an equality of temperature. A throttle valve at *c*, serves to regulate the draught, and to equalise it in the different experiments by means of the temperature of the effluent air. When the water has been heated to the given number of degrees, which should be the same in the different experiments, the fire may be extinguished, the remaining fuel weighed, and compared with the original quantity. Care should be taken to make the combustion as vivid and free from smoke as possible.

*d*. The quantity of heat disengaged by any combustible in the act of burning, is determined by the quantity of water evaporated. (Methods of Karmarsch,* Johnson,† De la Bêche and Playfair,‡ Brix,|| and others). Karmarsch ascertains the quantity of water which may be converted into steam in a boiler by one pound of the different kinds of fuel. Johnson and Brix employ a well-conducted boiler, and ascertain the quantity of water which may be converted into steam of 110° or 115° C. by means of one pound of fuel. This method, which, somewhat modified, has also been employed by Hartig,§ is the best and most useful. The results obtained by it correspond with those obtained by a calculation of the heating power from a chemical analysis of a fuel. Brix has based his calculations on a larger caloric unit than that above stated. He adopts as caloric unit the total heat of steam,

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* Mitthl. des Hannov. Gewerbe-Vereins, 1835, Lief. 5, p. 311.

† LIEBIG's Jahresber., 1850, p. 688.

‡ Polyt. Centr., 1849, p. 233.

|| BRIX, Untersuchungen über die Heizkraft der wichtigeren Brenmat. des Preuss. Staates: Berlin, 1853.

§ HARTIG, Untersuch. über die Heizkraft der Steinkohlen Sachsens: Leipzig, 1860.

at a temperature (110° to 115° C.) somewhat exceeding the boiling point, or, in other words, the quantity of heat which is required to convert one pound of water of 0° C. into steam of 110° or 115° C.

Johnson, De la Bêche and Playfair have adopted as the unit the latent heat of steam of 100° C., that is, the quantity of heat required to convert one pound of water into steam of 100° C. This caloric unit for centesimal degrees is, according to Regnault, 536.5. Peters prefers the unit suggested by English and American investigators to that of Brix, and on comparing the theoretical heating power of coal, calculated from the chemical composition, with the heating power ascertained by experiments in evaporating water, he adopted as caloric unit that quantity of heat which is required to convert 10 lbs. of water into steam of 100° C.

The following returns of trials at Woolwich Dockyard* between the 9th February, 1848, and the 31st March, 1858, will be found of great interest:—

| Description of the Fuel tried. | Numbers of trials from which the average results are deduced. | Pounds of Water evaporated to 1lb. coal consumed, calculated from 100° constant temperature of the feed water. | Cubic feet of Water evaporated per hour, calculated from 100° constant temperature of the feed water. | Percentage of Clinker. | Percentage of Ash. |
|---|---|---|---|---|---|
| *Welsh Coals.* | | | | | |
| Abercarn Black Vein.. .. .. .. | 1 | 9.01 | 46.49 | 1.25 | 4.46 |
| Aberdare steam coal .. .. .. .. | 1 | 8.98 | 48.81 | 1.72 | 5.93 |
| „ Fothergill's .. .. .. .. | 1 | 9.44 | 47.60 | 1.79 | 4.37 |
| „ Bwllfa .. .. .. .. .. | 2 | 9.40 | 50.28 | 1.43 | 5.75 |
| Bedwas.. .. .. .. .. .. .. .. | 1 | 8.35 | 45.30 | 2.08 | 6.16 |
| Birchgrove Graigola .. .. .. .. | 3 | 8.53 | 48.37 | 1.43 | 9.13 |
| Blaendare Big Seam .. .. .. .. | 1 | 8.28 | 43.76 | 3.34 | 5.10 |
| „ Merthyr .. .. .. .. | 1 | 9.06 | 47.68 | 3.12 | 6.14 |
| Blaengwurr Merthyr .. .. .. .. | 7 | 9.38 | 49.44 | 1.53 | 5.84 |
| Brymbo Main .. .. .. .. .. | 2 | 8.52 | 44.24 | 0.95 | 6.40 |
| „ 2-yard vein .. .. .. .. | 1 | 8.45 | 45.02 | 1.13 | 6.49 |
| „ 4-yard vein .. .. .. .. | 1 | 8.34 | 43.03 | 1.08 | 5.70 |
| „ steam coal .. .. .. .. | 2 | 7.95 | 50.47 | 1.57 | 4.81 |
| Bute Merthyr .. .. .. .. .. | 5 | 9.20 | 48.39 | 3.07 | 5.19 |
| Camnethan .. .. .. .. .. .. | 2 | 8.21 | 51.91 | 0.55 | 3.99 |
| Carr's Merthyr .. .. .. .. .. | 3 | 9.14 | 49.21 | 1.99 | 5.23 |
| Charcoal Vein .. .. .. .. .. | 1 | 8.98 | 46.79 | 1.95 | 5.06 |
| Coed Talon .. .. .. .. .. .. | 5 | 7.68 | 52.11 | 0.96 | 5.40 |
| Coleshill coal .. .. .. .. .. | 1 | 7.68 | 52.06 | 0.25 | 3.11 |
| „ Bagillt .. .. .. .. .. | 2 | 7.92 | 49.33 | 0.62 | 3.57 |

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* Ure's Dictionary of Arts and Mines, vol. ii., p. 409.

| Description of the Fuel tried. | Numbers of trials from which the average results are deduced. | Pounds of Water evaporated to 1 lb. coal consumed, calculated from 100° constant temperature of the feed water. | Cubic feet of Water evaporated per hour, calculated from 100° constant temperature of the feed water. | Percentage of Clinker. | Percentage of Ash. |
|---|---|---|---|---|---|
| Cwm Ammon | 4 | 8·60 | 45·02 | 1·75 | 3·61 |
| ,, | 6 | 8·93 | 45·93 | 2·01 | 5·27 |
| Cwmfrood Rock Vein | 1 | 8·72 | 46·88 | 2·11 | 4·18 |
| Ebbw Vale | 3 | 9·26 | 38·79 | 1·78 | 6·78 |
| ,, | 1 | 9·09 | 43·82 | 2·51 | 6·41 |
| Elled's Vein | 3 | 9·10 | 51·21 | 1·55 | 5·29 |
| Elsecar hard steam coal | 3 | 8·27 | 45·99 | 0·73 | 5·33 |
| Euloe Colliery | 2 | 8·28 | 48·36 | 1·31 | 3·71 |
| Garden Edge Colliery coal | 3 | 8·41 | 50·87 | 0·98 | 5·14 |
| Gellia Cadoxtan steam coal | 2 | 8·91 | 49·97 | 0·68 | 5·70 |
| ,, ,, ,, ,, | 2 | 8·54 | 43·83 | 0·87 | 6·21 |
| Golynos | 1 | 9·02 | 42·62 | 0·69 | 3·91 |
| Graigola steam coal | 3 | 8·89 | 35·59 | 0·42 | 6·69 |
| ,, ,, ,, (hand-picked) | 1 | 8·84 | 41·02 | 0·71 | 5·52 |
| Gwythen Charcoal Vein | 1 | 8·21 | 47·55 | 0·95 | 4·40 |
| ,, ,, ,, | 4 | 8·95 | 48·16 | 2·70 | 3·80 |
| Little Raith Lochgelly | 2 | 7·27 | 46·68 | 0·92 | 7·43 |
| Llanelly | 1 | 8·43 | 46·43 | 1·96 | 6·80 |
| Llangenneck | 2 | 8·81 | 46·52 | 2·36 | 6·41 |
| ,, (hand-picked) | 2 | 8·44 | 44·92 | 2·03 | 5·73 |
| Lochgelly coal | 2 | 7·66 | 46·06 | 0·10 | 4·12 |
| Machen Black Vein | 1 | 8·81 | 50·44 | 2·10 | 5·39 |
| ,, Rock Vein | 1 | 8·32 | 47·27 | 1·37 | 4·78 |
| Merthyr | 28 | 8·78 | 45·42 | 1·02 | 5·54 |
| ,, | 4 | 9·06 | 48·17 | 1·66 | 4·56 |
| ,, Aberammon | 1 | 8·63 | 47·72 | 1·49 | 3·79 |
| ,, Aberdare | 3 | 8·75 | 46·78 | 1·61 | 4·06 |
| ,, ,, Fothergill's | 43 | 8·51 | 44·79 | 1·47 | 4·53 |
| ,, Crosfield | 2 | 9·37 | 45·14 | 1·25 | 6·38 |
| ,, ,, and Gadley's | 1 | 8·66 | 46·12 | 0·91 | 7·53 |
| ,, (hand-picked) | 8 | 8·92 | 45·84 | 1·13 | 4·82 |
| ,, Nixon's | 6 | 8·78 | 45·54 | 0·98 | 4·34 |
| ,, Wensleydale | 1 | 8·91 | 45·84 | 0·61 | 6·49 |
| ,, Wood's | 1 | 8·87 | 43·70 | 0·67 | 5·68 |
| Morfa steam coal | 1 | 8·53 | 44·63 | 1·12 | 4·63 |
| ,, ,, ,, Vivian's | 2 | 8·60 | 44·94 | 1·30 | 5·23 |
| Nevill's Llanelly | 2 | 8·56 | 47·59 | 2·03 | 5·80 |
| New Black Vein steam coal | 2 | 9·56 | 50·67 | 0·79 | 5·75 |
| Newelline | 1 | 8·97 | 48·25 | 2·21 | 6·25 |
| Powell's Duffryn | 1 | 9·08 | 48·26 | 1·35 | 6·81 |
| Resolven | 9 | 9·06 | 48·10 | 1·77 | 5·48 |
| ,, (hand-picked) | 1 | 8·64 | 45·32 | 0·54 | 4·35 |
| ,, ,, | 1 | 9·15 | 46·79 | 1·75 | 4·40 |
| Risca Rock Vein | 1 | 8·26 | 46·67 | 1·87 | 5·22 |
| Rock Vein | 2 | 8·60 | 48·11 | 2·39 | 5·89 |
| Squborwen Merthyr | 12 | 8·93 | 46·51 | 1·85 | 6·00 |
| Thomas's Merthyr | 2 | 9·28 | 49·99 | 1·84 | 4·61 |
| Tillery Big Vein | 2 | 8·89 | 51·99 | 1·07 | 4·57 |
| Wagnus Merthyr | 2 | 8·79 | 47·25 | 1·76 | 6·48 |
| Waynes Merthyr | 1 | 8·98 | 48·43 | 1·79 | 5·23 |
| Welsh coal | 2 | 9·33 | 48·62 | 1·75 | 6·16 |

| Description of the Fuel tried. | Numbers of trials from which the average results are deduced. | Pounds of Water evaporated to 1 lb. coal consumed, calculated from 100° constant temperature of the feed water. | Cubic feet of Water evaporated per hour, calculated from 100° constant temperature of the feed water. | Percentage of Clinker. | Percentage of Ash. |
|---|---|---|---|---|---|
| *North Country Coal.* | | | | | |
| Alloa Colliery | 2 | 8·89 | 55·07 | 1·01 | 5·02 |
| Atherton steam coal | 4 | 8·22 | 48·76 | 0·74 | 4·93 |
| Barlieth and Dollar's steam coal | 1 | 7·95 | 49·45 | 0·46 | 4·17 |
| ,, ,, ,, ,, ,, | 4 | 8·32 | 49·39 | 1·29 | 4·17 |
| Bates's Hartley | 1 | 6·71 | 45·66 | 2·12 | 4·12 |
| ,, West Hartley | 3 | 7·70 | 46·41 | 1·34 | 5·23 |
| Bebside Colliery coal | 4 | 8·14 | 49·82 | 0·95 | 4·60 |
| Bell's Primrose | 3 | 9·46 | 45·67 | 2·40 | 6·68 |
| Bourtrechill coal | 1 | 7·56 | 45·96 | 1·27 | 4·67 |
| Buddle's Hartley | 23 | 7·79 | 47·98 | 1·49 | 4·08 |
| ,, West Hartley | 38 | 8·05 | 48·34 | 1·41 | 4·47 |
| Carr's Hartley | 9 | 8·05 | 48·63 | 1·71 | 3·76 |
| Clackmannan | 3 | 8·09 | 45·39 | 0·67 | 4·76 |
| Cuttlehill | 1 | 7·72 | 42·57 | — | 5·74 |
| Derwentwater, Radcliffe Colliery | 1 | 8·27 | 50·22 | 1·10 | 3·82 |
| ,, West Hartley | 1 | 7·69 | 48·23 | 1·67 | 4·72 |
| Eardson's Hartley | 3 | 8·25 | 50·12 | 0·71 | 4·88 |
| Garforth's Hartley | 2 | 8·06 | 50·11 | 0·61 | 5·75 |
| Garforth steam coal | 2 | 7·12 | 40·33 | 1·26 | 5·60 |
| Garswood Park | 1 | 7·99 | 51·61 | 1·19 | 5·29 |
| Gawber Hall | 2 | 8·14 | 42·49 | 1·05 | 4·11 |
| ,, ,, steam coal | 5 | 7·84 | 43·01 | 1·25 | 5·80 |
| Gower coal | 2 | 7·83 | 44·58 | 0·92 | 5·28 |
| Grey's Broomhill | 5 | 8·04 | 48·87 | 1·14 | 5·66 |
| Grimsby coal, Sheffield Railway | 1 | 7·46 | 45·84 | 1·69 | 4·24 |
| Halsnead coal | 3 | 7·48 | 47·23 | 1·24 | 3·69 |
| Hartley coal | 2 | 7·74 | 45·78 | 1·06 | 5·77 |
| ,, Bate's West | 1 | 7·39 | 48·27 | 0·66 | 7·07 |
| ,, Belmont | 2 | 8·40 | 46·30 | 1·43 | 3·97 |
| ,, Buddle's | 4 | 7·80 | 45·61 | 1·15 | 4·11 |
| ,, ,, West | 17 | 7·82 | 46·33 | 1·28 | 4·09 |
| ,, Carr's | 15 | 8·19 | 45·45 | 1·22 | 3·93 |
| ,, ,, West | 1 | 8·35 | 48·43 | 1·00 | 5·88 |
| ,, Clifton West | 3 | 7·91 | 45·02 | 1·48 | 4·57 |
| ,, Cowpen | 2 | 7·63 | 44·87 | 0·73 | 5·94 |
| ,, Fenham's | 21 | 8·53 | 43·47 | 2·07 | 5·10 |
| ,, ,, West | 1 | 8·87 | 42·41 | 2·89 | 6·25 |
| ,, Hedley's | 1 | 8·40 | 47·02 | 1·29 | 2·91 |
| ,, Hetton West | 3 | 8·45 | 47·39 | 1·18 | 6·98 |
| ,, Howard's West Netherton | 2 | 7·67 | 46·22 | 1·35 | 6·80 |
| ,, Jonassohn's | 4 | 8·09 | 49·12 | 0·88 | 5·34 |
| ,, Longridge West | 1 | 7·82 | 47·57 | 1·46 | 3·75 |
| ,, ,, best | 2 | 7·86 | 46·10 | 1·18 | 3·39 |
| ,, Morpeth | 6 | 7·87 | 47·58 | 1·52 | 4·70 |
| ,, Newcastle | 2 | 8·49 | 45·41 | 2·07 | 5·73 |
| ,, Wellington West | 1 | 8·89 | 42·48 | 1·37 | 5·09 |
| ,, Whitworth | 2 | 8·40 | 42·88 | 1·79 | 3·81 |
| ,, Willington West | 1 | 8·93 | 43·11 | 1·35 | 3·65 |
| Hastings Hartley | 1 | 7·73 | 47·45 | 1·16 | 3·91 |
| Heaton Colliery | 3 | 8·79 | 46·20 | 2·38 | 6·29 |

| Description of the Fuel tried. | Numbers of trials from which the average results are deduced. | Pounds of Water evaporated to 1 lb. coal consumed, calculated from 100° constant temperature of the feed water. | Cubic feet of Water evaporated per hour, calculated from 100° constant temperature of the feed water. | Percentage of Clinker. | Percentage of Ash. |
|---|---|---|---|---|---|
| Howard's West Hartley | 17 | 8·08 | 49·58 | 1·24 | 4·69 |
| ,, Netherton | 6 | 9·58 | 58·36 | 2·22 | 5·14 |
| Hoyland Colliery | 2 | 8·70 | 48·98 | 0·55 | 3·95 |
| ,, and Elsecar | 3 | 8·15 | 45·78 | 0·67 | 4·12 |
| Ince Hall coal | 2 | 7·72 | 45·22 | 1·44 | 5·40 |
| ,, ,, ,, | 1 | 8·04 | 45·62 | 1·08 | 3·76 |
| Kilnhurst Hard | 1 | 7·74 | 45·77 | 1·21 | 3·24 |
| Land Engine coal | 1 | 7·86 | 48·09 | 1·51 | 4·68 |
| Lindsay Mine | 2 | 7·90 | 42·86 | 2·04 | 2·83 |
| Lord Rosslyn's coal | 1 | 6·11 | 42·66 | 1·67 | 6·08 |
| ,, Ward's steam coal | 2 | 7·60 | 51·30 | 1·36 | 4·37 |
| Lumley's steam coal | 2 | 8·54 | 37·40 | 1·01 | 6·63 |
| Lundhill hard coal | 2 | 8·84 | 49·19 | 1·22 | 3·92 |
| ,, soft coal | 3 | 8·55 | 50·42 | 1·60 | 3·87 |
| Lyon's West Hartley | 4 | 8·71 | 52·73 | 1·17 | 4·95 |
| Midgeholme | 2 | 9·25 | 44·26 | 0·59 | 6·16 |
| North Country coal | 1 | 8·16 | 50·14 | 1·47 | 5·03 |
| North Gawber steam coal | 1 | 7·71 | 45·04 | 0·85 | 4·59 |
| Oaks Colliery | 4 | 7·75 | 44·91 | 0·42 | 6·03 |
| Orrell steam coal | 2 | 8·78 | 42·61 | 1·54 | 6·82 |
| Ramsay's Adair's Main | 3 | 8·65 | 43·10 | 1·01 | 5·35 |
| Ravensworth's Hartley | 3 | 7·77 | 48·44 | 1·63 | 4·79 |
| Rochsole's Colliery | 3 | 7·76 | 46·54 | 1·67 | 2·82 |
| Skerrington coal | 3 | 7·81 | 47·60 | 1·03 | 3·63 |
| ,, Colliery | 2 | 8·69 | 52·45 | 1·67 | 5·73 |
| Splint coal | 3 | 7·25 | 42·29 | 0·67 | 4·20 |
| St. Helen's Tees | 3 | 9·19 | 54·15 | 0·33 | 4·78 |
| Stavely Main coal | 8 | 7·69 | 41·27 | 0·71 | 4·26 |
| Strangeways Colliery, 3 feet seam | 1 | 7·91 | 48·17 | 0·87 | 5·28 |
| Walthen House, or New House | 1 | 8·62 | 49·11 | 2·85 | 5·07 |
| Washington's West Hartley | 2 | 8·63 | 48·26 | 2·91 | 5·98 |
| Wather House steam coal | 4 | 7·84 | 47·75 | 2·46 | 3·64 |
| Wellington Hartley | 1 | 7·84 | 49·92 | 1·51 | 4·09 |
| Wellwood Colliery | 2 | 7·97 | 50·25 | 1·05 | 7·05 |
| West Hartley | 2 | 8·08 | 47·97 | 1·79 | 4·46 |
| Whitefield Colliery | 2 | 9·49 | 52·17 | 0·05 | 4·42 |
| Whitworth Park | 2 | 8·79 | 46·49 | 0·92 | 5·14 |
| Wigan, 4 feet seam | 1 | 7·97 | 45·38 | 1·64 | 5·75 |
| Wombwell Main | 3 | 8·26 | 44·98 | 0·81 | 4·50 |
| Yate Deep Vein | 3 | 8·26 | 51·11 | 3·10 | 4·47 |
| *Anthracite coal* | 2 | 9·58 | 35·43 | 1·48 | 10·32 |
| ,, ,, | 4 | 6·87 | 26·64 | 0·18 | 2·42 |
| ,, ,, Bonville's Court | 3 | 8·35 | 31·19 | 1·02 | 5·57 |
| ,, ,, Killgetty | 6 | 9·02 | 42·68 | 0·64 | 11·3 |
| ,, ,, Watney's | 4 | 8·87 | 41·44 | 1·48 | 6·58 |
| *Cambrian steam fuel* | 3 | 8·32 | 45·45 | 1·17 | 5·81 |
| *Chilian coal* | 1 | 7·29 | 38·83 | 2·80 | 3·33 |
| *Coke consolidated* | 2 | 8·76 | 19·47 | 0·14 | 19·11 |
| *Patent fuel* | 1 | 8·59 | 48·85 | 1·97 | 4·21 |
| ,, ,, | 3 | 9·11 | 48·20 | 2·40 | 3·86 |
| ,, ,, Captain Cochrane's | 1 | 4·01 | 22·09 | 7·76 | 32·50 |

| Description of the Fuel tried. | Numbers of trials from which the average results are deduced. | Pounds of Water evaporated to 1 lb. coal consumed, calculated from 100° constant temperature of the feed water. | Cubic feet of Water evaporated per hour, calculated from 100° constant temperature of the feed water. | Percentage of Clinker. | Percentage of Ash. |
|---|---|---|---|---|---|
| *Patent fuel*, Holland's .. .. .. .. | 6 | 7·94 | 39·51 | 1·70 | 6·30 |
| „ „ Lyon's .. .. .. .. .. | 2 | 8·98 | 47·40 | 2·86 | 4·37 |
| „ „ Temperley's .. .. .. .. | 3 | 8·50 | 42·45 | 0·99 | 7·19 |
| „ „ Warlich's .. .. .. .. | 8 | 8·70 | 44·12 | 2·40 | 7·64 |
| „ „ „ .. .. .. .. | 4 | 9·16 | 46·47 | 3·03 | 5·62 |
| *Port Adelaide* .. .. .. .. .. .. | 1 | 6·44 | 32·30 | 7·42 | 23·35 |
| *Singapore coal* .. .. .. .. .. .. | 1 | 6·97 | 48·77 | — | 9·99 |
| *St. Domingo* (Samana) .. .. .. .. | 1 | 1·29 | 10·59 | — | 18·00 |

## The Theoretical Heating Power, Calculated from the Composition of the Fuel.

According to Welter's theory, the absolute heating power of carbon and hydrogen stands in direct proportion to the oxygen required for burning those substances. This theory is based upon the circumstance that according to stöchiometrical calculation, one part in weight of hydrogen consumes, on combustion, three times more oxygen than carbon, and that, according to the older statements (page 321), the absolute heating power of hydrogen and carbon stands in the proportion of three to one. The quantity of oxygen required for burning fuel may be calculated from its composition.

The oxygen contained in the fuel is not without effect in the process of combustion, but even impairs the heating power, as it binds an equivalent quantity of carbon or hydrogen, in consequence of which a corresponding amount of the latter substances creates no heat, and must be deducted from the combustible components of the fuel. More recent investigations of the absolute heating power of hydrogen and carbon have ascertained their proper proportion to be 4·2 to 1; this, therefore, accounts for Welter's theory not being more generally employed.

The latest investigations of the caloric units have proved that Welter's theory or law is correct with regard to carbonic oxide and hydrogen. Fourteen parts in weight of carbonic oxide, when burnt to carbonic acid, absorb eight parts of oxygen, and produce 14 × 2466 = 34524 units of heat, if calculated with the application of Dulong's ratio; these caloric units closely correspond with the absolute heating power of hydrogen = 34800, as it is determined by Dulong. One part in weight of hydrogen likewise requires eight parts of oxygen for its combustion.

Peters* proposes more simple formulæ for calculating the absolute heating power from the chemical analysis of fuel. The results obtained by these formulæ exactly correspond with those obtained by Brix (page 321) in his experiments with coal.

If C represents the amount of carbon contained in 100 parts of an organic substance, H such an amount of hydrogen, and A the percentage of foreign admixtures (water, sulphur, and ash) the absolute heating power of 100 parts of any fuel will be—

$$E = (2{\cdot}3\,C + 7{\cdot}2\,H - 80)\,\frac{100 - A}{100}$$

Mineral coal, for instance, containing eight parts of foreign substances, = A, in 100 parts, and organic substances in the following proportion: 90 C, 5 H, and 5 N and O, it will follow that—

$$E = (2{\cdot}3 \times 90 + 7{\cdot}2 \times 5 - 80)\,0{\cdot}92 = 149{\cdot}96.$$

149·96 therefore represents the heating power, in caloric units, which may be produced by the perfect combustion of 100 parts in weight of mineral coal.

Stein† has calculated the theoretical heating power of the Saxony coal from its chemical composition; but he considers two-thirds of this amount as the practical heating power, which may be obtained in well-constructed fire-places.

Berthier's method for ascertaining the comparative caloric power of any combustible matter, by means of litharge, is fully described in Mitchell's "Assaying."

Forchhammer‡ recommends the employment of a mixture of three parts in weight of litharge and one part of chloride of lead, instead of pure litharge, as this mixture admits of a quicker smelting if employed in such quantities as is usual with litharge alone.

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* Zeitschr. des Vereins deutcher Ingenieure, ii., 223. Berggeist, 1859, Nos. 15, 66.

† B. u. h. Ztg., 1857, p. 382.

‡ Bgwkfd., xi., 30.

Pure carbon produces, with pure litharge, thirty-four times its weight of lead ; charcoal, containing 1 or 1½ per cent of ash, produces only twenty-nine or thirty times its weight.

Favre and Silbermann's caloric unit of carbon = 8086 is accepted; each part of lead produced by the fuel will correspond to $\frac{8086}{34}$ = 238 units of heat, and to only 230 units if Despretz's ratio of 7815 is accepted.

Water and pyrites contained in the fuel necessitate further corrections.

Berthier's method, when based upon Welter's theory, does not give absolutely correct results; they deviate, however, but little from the truth, and, owing to its simplicity, this method is still in use, and of practical value.* The results are, at the very highest, only one-ninth smaller than those found by calculation from analyses of the fuel, and the richer in carbon the fuel is, and the less carbonic oxide that has been formed by a careful execution of the assay,† the nearer they approximate to the theoretical results.

**Comparison of the Theoretical Heating Power with the Practical Results.**—The theoretical heating power is always higher than that found by experience, because—

1. The combustion is never quite perfect, as if there is a lack of atmospheric air, a partial carbonisation will take place, and if too much is admitted, the surplus of oxygen and nitrogen requires to be heated. The cinders falling through the grate also cause loss of heat in the apparatus.

2. The hot products of combustion never transmit all their heat to the substance to be heated; part of it is lost by radiation from the grate, the furnace walling, &c., another part escapes into the chimney along with the products of combustion, while another is absorbed by the hygroscopic water present, &c. Bunsen estimates this loss, in iron blast furnaces, to be 75 per cent, and still more in reverberatory furnaces.

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* Erdm., J. f. pr. Chem., xvii., 65. Oesterr. Ztschr., 1853, p. 34; 1856, p. 249.

† Dingl., Bd. 146, p. 138. Polyt. Centr., 1858, No. 2, p. 123.

**Devices for Increasing the Heating Power Obtained in Practice.**—In order practically to produce a heating power approaching the theoretical result, the combustion of the fuel must be as perfect as possible (smoke consuming apparatus, a judicious admission of air, a careful stirring of the fire, so as to avoid or lessen the loss by the formation of cinder, previous heating of the fuel or the air of combustion, &c.); care must also be taken that the greater part of the heat produced is transmitted to the substance to be heated. The latter requirement may be facilitated by perfectly drying the furnaces, the substances to be heated, the fuel and the air of combustion, by a judicious selection of the fuel, a suitable division of the substances under treatment, a suitable construction of the furnace, a regulation of air of combustion, &c. The waste gases escaping from the furnace must be further utilised (use of the waste gases from the furnace mouth, of the radiating heat of the furnace walling for drying fuel, ore, heating of blast, boilers, &c.)

Brix's experiments and Peters's calculations have taught that, with mineral coal, the theoretical heating power is larger than that obtained in practice by a nearly constant coefficient (in medium 0·664). The practically obtainable heating power may therefore be calculated by multiplying the theoretical power by 0·664 or by ⅔.

Schinz* has stated the composition of various kinds of fuel, and the quantities of heat which they may produce, to be as follows:—

| | Ash, Water, Nitrogen. | Carbon. | Free Hydrogen. | 1 lb. of Carbon produces 14,500 units of heat. F° | 1 lb. of Hydrogen produces 62,000 units of heat. F° | Total units of Heat. |
|---|---|---|---|---|---|---|
| Air-Dried Wood .. | 0·600 | 0·394 | 0·007 | 5713 | 434 | 6147 (F° |
| Bituminous Coal .. | 0·150 | 0·815 | 0·357 | 11817 | 2170 | 13987 ,, |
| Charcoal .. .. .. | 0·070 | 0·930 | — | 13485 | — | 13485 ,, |
| Coke .. .. .. .. | 0·150 | 0·850 | — | 12325 | — | 12325 ,, |
| Anthracite .. .. | 0·061 | 0·915 | 0·0244 | 13267 | 1513 | 14780 ,, |

The quantities of heat are considerably decreased if the carbon, owing to a want of air, is burnt to carbonic oxide instead of carbonic acid. The quantity of heat with 1 lb. of carbon will then decrease from 14,500 to 2442 units, and with the kinds of fuel enumerated, to 1397, 4160, 2271, 2075, and 3747 units per lb. respectively, which is equal to a loss of heat of 77, 70, 83, 83, and 75 per cent respectively.

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* Dingl., Bd. 142, p. 261. B. u. h. Ztg., 1857, p. 75.

According to theoretical calculation, the above-named fuels require, for perfect combustion, 60·3, 133·7, 135·1, 123·5, and 143·6 cubic feet of air per lb. respectively; in reality, however, a surplus of air occasionally occurs, and, at other times, a want of it, according to whether the fuel lies on the grate in a thin or in a thick layer, and whether the draught is more or less strong. In practice, a very thick layer of fuel on the grate is employed, if the production of an intense fire is intended. Schinz calls units of heat that quantity of heat which is required to raise the temperature of 1 lb. of water by 1° Fahr. Only 0·2377 unit of heat is required for heating 1 lb. of air 1°. This unit is termed the specific heat of air. 1 cubic foot of air requires 0·018575 unit of heat to raise it 1°.

2. **The Specific Heating Power** represents the heat produced from a certain volume of fuel. It may be ascertained by multiplying the absolute heating power by the specific gravity of the fuel.

*Example.*—For a certain process, in a reverberatory furnace, 240 cubic feet of pine wood are consumed. It is a question how many cubic feet of mineral coal can replace that quantity of wood, if the grate is suitably re-constructed, and supposing

1 part of pine wood to reduce 14·5 parts of lead,
and 1 „ coal „ 31·0 „ „
and the specific gravity of pine wood to be = 0·472,
and „ „ „ coal „ = 1·279,

the specific heating power of pine wood and coal are proportionate to the products of their absolute heating power into their specific gravities, that is as

$$14{\cdot}5 \times 0{\cdot}472 : 31{\cdot}0 \times 1{\cdot}279 = 6{\cdot}84 \text{ to } 39{\cdot}64,$$

consequently it will be possible to replace 6·84 volumes of coal by 39·64 volumes of wood, or 240 cubic feet of wood by a quantity of coal amounting to $\frac{240 \times 6{\cdot}84}{39{\cdot}64} = 41{\cdot}4$ cubic feet.

According to Peters,* more useful and practical results are obtained if the contents of a certain volume (such as a a load or bushel) are repeatedly weighed,† instead of making use of the specific gravity, as the weight of a definite large volume of various coal, &c., is by no means always in proportion with the respective specific gravity, owing to the variable shape and size of the pieces.

## B. Determination of the Pyrometric Heating Power.

By pyrometric heating power is meant the degree of temperature which may be obtained by completely burning the fuel. This power depends, not only on the composition of the fuel, but also, and chiefly, on the air of combustion introduced, as well as on the time required for its combustion, and this again is dependent on the amount of water contained in the fuel, on its porosity, and state of division.

The pyrometric heating power may be determined by calculation, and by the application of pyrometers.

Scheerer‡ calculates the pyrometric heating power from formulæ, which are based upon the absolute heating power as determined by Dulong, Grassi, Favre and Silbermann, (page 321), on the relative weight of the fuel, and the specific heat of the products of combustion produced from the fuel. He gives the following examples of this heating power:—

| | In Oxygen. | In Air. |
|---|---|---|
| Carbon . . . = | 9873° C. | 2458° C. |
| If burnt to carbonic acid— | | |
| Carbon . . | — | 1310° C. |
| If burnt to carbonic oxide— | | |
| Carbonic oxide = | 5316°—7090° C. | 2121°—2828° C. |
| Carburetted hydrogen (CH) = | 6308° C. | 2290° C. |
| Carburetted hydrogen ($CH_2$) = | 4766° C. | 1935° C. |
| Hydrogen . . = | 4073° C. | 2080° C. |

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* Berggeist, 1859, No. 18, p. 146.

† B. u. h. Ztg., 1859, p. 151.

‡ SCHEERER, Metallurgie, i., 145, 385. V. HERDER's Erläuterungen der vorzüglichsten Apparate zur Erwärmung der Gebläseluft, 1840 (Beilage).

Dalton and Grassi give a lower pyrometric heating power for carbonic oxide than Dulong, and Favre and Silbermann. According to the latter investigators, carbonic oxide, on combustion in atmospheric air, produces a higher degree of heat than carbon, which may be possible, owing to the high absolute heating power of carbonic oxide, and to the circumstance that one part by weight of carbonic oxide, on combustion in atmospheric air, produces only 2·47 parts by weight of gaseous products, whilst one part of carbon, under similar circumstances, yields 12·57 parts, the nitrogen of the atmospheric air being included in both cases.

When the carbonic acid which has been formed before the tuyere of a blast furnace is converted into carbonic oxide by means of glowing coal, a lowering of the temperature by 2458—1310=1148° C. will be observed, the reason of which is that a chemical solution and not a combustion of carbon takes place, in which process the solid carbon assumes the gaseous form, and absorbs heat. This decrease of temperature amounts, according to Dulong, to 1316° C., and 1200° C. may be considered as the average amount.

This explains why the kinds of compact fuel (coke, anthracite, hard charcoal) possess a higher pyrometric heating power than loose fuel, such as brown coal, turf, wood, soft charcoal. As an equal volume of compact fuel has less surface than loose fuel, less quantity of carbonic acid formed in combustion will be converted into carbonic oxide. Mitscherlich states that the medium diameter of a cell in charcoal measures 1-2400th inch. On comparing the weight of dry charcoal with that of a piece impregnated with water, it will be found that the surface of the cells of a piece of charcoal weighing 0·9565 gr., measures about 73 square feet.

These statements explain why carbonised kinds of fuel,* rich in carbon, have a greater pyrometric heating power than the inflammable raw fuel, rich in hydrogen. The case is just the reverse with regard to the absolute heating power, for the reason that, on being heated to a certain degree, the watery vapour formed by the combustion of hydrogen, absorbs nearly four times as much heat as carbonic acid.

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* B. u. h. Ztg., 1853, p. 557.

For combustion there are required—

| Part by Weight. | Parts by Weight. | | Parts by Weight. | | | |
|---|---|---|---|---|---|---|
| 1 C | +2·67 O, | in order to form | 3·67 $CO_2$ | | | |
| 1 C | +1·33 O, | ,, ,, | 2·33 $CO_2$ | | | |
| 1 CO | +0·57 O, | ,, ,, | 1·57 $CO_2$ | | | |
| 1 CH | +3·43 O, | ,, ,, | 3·14 $CO_2$ | and | 1·29 | Water. |
| 1 $CH_2$ | +4·00 O, | ,, ,, | 2·75 $CO_2$ | ,, | 2·25 | ,, |
| 1 H | +8·00 O, | ,, ,, | — $CO_2$ | ,, | 9·00 | ,, |
| Part by Volume. | Parts by Volume. | | Parts by Volume. | | Parts by Volume. | |
| 1 CO | +0·50 O, | ,, ,, | 1·00 $CO_2$ | ,, | — | ,, |
| 1 H | +6·50 O, | ,, ,, | — $CO_2$ | ,, | 1·00 | ,, |
| 1 CH | +2·00 O, | ,, ,, | 1·00 $CO_2$ | ,, | 2·00 | ,, |
| 1 $CH_2$ | +3·00 O, | ,, ,, | 2·00 $CO_2$ | ,, | 2·00 | ,, |

The various heating powers are calculated by Scheerer at atmospheric tension, and are to be considered as "maxima," as the effect really obtained is more or less below the theoretical one. The calculated ratios at once admit, however, of a comparison of the effects of various kinds of fuel. When fuel is burnt as perfectly as possible by a judicious admission of air, which, if required, is previously heated, a pyrometric heating power may be obtained, which nearly approaches the theoretical pyrometric heating power. The pyrometric heating power may be frequently increased by a judicious preparation of the fuel (pressing of the turf, washing of the mineral coal, &c.), as also by introducing steam along with the blast, and more especially by burning the greatest possible number of particles of fuel in a certain time. The latter operation may be effected by a suitable division of the fuel, and by the application of blast or draught.

Scheerer has propounded the view, and, in fact, based his theory upon it, that every combustible body could burn *in maximo* only with that degree of temperature which corresponds to the quantity of oxygen required for perfect combustion, and which enters the products of combustion whilst being modified by the admixture of other gases. According to Heintz, Steinheil, and Exter,* this view is correct with regard to the *quantity* of heat, but not with regard to the *intensity*, or the pyrometric heating power, which, in certain limits, may be raised at will if the combustion is effected at a higher tension than that of the atmosphere. This may be attained in reverberatory furnaces, by introducing air and gas into the fire-place under a higher pressure than that with which the products of combustion escape from the furnace. Such a pressure admits of the perfect combustion of twice or three times the quantity by weight of a combustible body, in the same space and the same time; this space must, therefore, contain twice or three times the quantity of heat, which, according to Mariotte's and Gay-Lussac's law, modified by Dulong's determination of the specific heat in constant volume, may be ascertained in the measured pressure of the hot gases. The supposition that carbon, on burning in oxygen and atmospheric air, could not produce a higher temperature than 9873° C. and 2458° C. respectively, is, therefore, only correct if such combustion takes place at atmospheric tension. Based upon these facts, the before-mentioned investigators have taken out patents by which they profess to raise the pyrometric heating power of any combustible matter.

According to Schinz,* the temperature of a fire may be calculated from the composition of a fuel, and the quality and quantity of the products of combustion; this temperature varies according to whether—

1. Perfect combustion takes place with the quantities of air which are theoretically required.

2. Perfect combustion takes place with double the quantity of air that is used in most fire-places where no great intensity of heat is required.

3. Imperfect combustion takes place, when part of the fuel (about one-half) escapes as carbonic oxide.

These three cases yield the following results:—

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* Bgwkfd., xviii., 588. Polyt. Centr., 1855, p. 1368.

† Dingl., Bd. 142, p. 261. B. u. h. Ztg., 1857, p. 75.

| | Perfect Combustion Without a Surplus of Air. | Perfect Combustion With a Surplus of Air. | Imperfect Combustion. |
|---|---|---|---|
| | Degrees Fahr. | Degrees Fahr. | Degrees Fahr. |
| Air-dried wood . . | 4120 | 2318 | 2949 |
| Bituminous coal . | 5029 | 2653 | 4113 |
| Charcoal . . . . | 4881 | 2553 | 3770 |
| Coke . . . . . . | 4881 | 2554 | 3651 |
| Anthracite . . . | 4956 | 2592 | 3949 |

The results of the first column are merely theoretical; those of the second correspond to practical experience; and those of the third are variable according to whether a thick or thin layer of fuel is kept on the grate, and whether the draught is stronger or weaker. The results adopted in the first table are the most favourable ones. The second method of combustion is applied when the production of lower degrees of temperature only is intended, such, for example, as are applied to heating a boiler, &c., and it may give rise to a considerable loss of temperature by the escape of hot products of combustion. The third method of combustion is frequently employed in metallurgical operations for the production of higher degrees of temperature, and, even under the most favourable circumstances, a loss of 40 per cent of heat will always take place.

**Pyrometers.**—The pyrometric heating power may be ascertained by means of pyrometers,* which method, however, is not quite exact, owing to the imperfection of the instruments, besides which the application of pyrometers frequently presents great difficulties.

The pyrometers practically employed are generally based upon the following principles:†—

*a.* **Pyrometers Based upon the Modification of the Volume of any Substance.**—This substance is usually metal, and only that metal can be applied which, at an increased temperature, expands as uniformly as possible.

Mercury pyrometers, having a prolonged scale up to 360° C., only admit of a limited use, and do not give exact results above 100° C., on account of the non-uniform expansion of mercury. Usually they are only employed for the determination of the temperature of the hot blast.

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* Merbach, Anwendung der erhitzten Gebläseluft im Gebdete der Metallurgie, 1840, p. 289.

† Bgwkfd., x., 497.

The older kinds of metal pyrometers admit of a measurement of the expansion of metals at different degrees of temperature, but they do not register those degrees themselves.

A number of metal pyrometers have more recently been constructed by Guyton de Morveau, Daniell, Neumann and Petersen, Gibbon, Siemens, and others.

Guyton employs a rod of platinum, one end of which is fixed to a plate of clay, and exposed to the temperature to be determined; the other end presses against the short arm of a lever as soon as expansion takes place, and thus turns the long arm of the lever, which, serving as a hand of a sextant, enables the degrees to be observed. This apparatus has one disadvantage, namely, that the sextant is heated at the same time with the rod of platinum; and this modifies and spoils it.

Daniell's pyrometer is described in Mitchell's "Assaying."

Neumann and Petersen's pyrometer is composed of rods of platinum and iron; it is of similar construction to Guyton's pyrometer, though with some improvements.

Stöhrer's* pyrometer is made of strips of steel and zinc. Kahl† employed strips of brass and steel, in the shape of screws, measuring temperatures up to 440° C.

The pyrometers mostly used for measuring the temperature of hot blast consist of strips of metal, which are soldered together, wound up in a spiral form, and fixed with one end into a box; the other end is connected with a hand moving over a dial. A change of temperature will modify the windings of the spiral, and thus move the hand, causing the degree of temperature to be indicated on the dial.

Clay pyrometers were invented by Wedgwood in 1782; their construction is based upon the variable degree of contraction which clay undergoes at high temperatures. Clay cylinders are exposed to the temperature to be determined, and then placed between two diverging bars, which are provided with a scale of 240°. The stronger the clay cylinders are heated, the more they will have contracted,* and the deeper it may be placed between the diverging bars.

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* Bgwkfd., vii., 463.

† Erdm., J. f. pr. Chem., Bd. 67, p. 401.

According to Wedgwood, the zero of the scale of his pyrometer corresponds to 1077·5° F. = 580° C., and each degree to 132° F. = 73⅓° C. But other investigators have held different opinions on this point. Prechtl considers the zero to be equal to 1000° F. = 538° C., Meissner to 1044° F. = 562° C., Naumann to 1077° F. = 580° C.; according to Prechtl and Naumann, 1° Wedgwood is equal to 130⅓° F., and according to other investigators, to 139° F.†

This pyrometer was formerly in general use, but since it has been proved that the clay cylinders contract in exactly the same manner when exposed to a lower heat for a longer time, as they do when exposed to a higher temperature for a shorter time, they have, in a greater or less degree, fallen into disuse.

Air pyrometers were first proposed by Schmidt in 1804, and afterwards improved by Petersen and Pouillet. They are formed of a platinum vessel, in connection with a double-bent, narrow, glass tube, the arms of which are filled with water, mercury, or sulphuric acid. When the vessel is exposed to the temperature to be ascertained, the air contained in it will expand, and make the fluid rise in the graduated arm of the glass tube.

Erman and Herter‡ in measuring the permanent expansion of cast-iron by means of an air pyrometer, closed the latter with a cock after the experiment was finished, and opened it again under water after the apparatus had become cold; they then made use of the quantity by weight of water entering the apparatus, for calculating the temperature which the pyrometer contained in heated state.

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* On the Contraction of Clay:—A. Brogniart, Traité des Arts Céramiques, 2 édit. par Salvétat: Paris, 1854, tom. i., p. 262. Hausmann, Molecularbewegungen, 1856, p. 15.

† The thermometric degrees may be reduced to the various scales by the following formulæ, in which *n* represents the given number of degrees:—

1. $n\,R = \frac{5}{4}\,n\,C.$
2. $n\,R = (\frac{9}{4}\,n + 32)\,F.$
3. $n\,C = \frac{4}{5}\,n\,R.$
4. $n\,C = (\frac{9}{5}\,n + 32)\,F.$
5. $n\,F = (n - 32 . \frac{5}{9})\,C.$
6. $n\,F = (n - 32 . \frac{4}{9})\,R.$

*Example.* How many degrees of Fahrenheit are 30° C.?—According to formula 4, 30° C. = $(\frac{9}{5}\,30 + 32)$ F. = 86° F.

‡ Bgwkfd., xix., 206.

*b.* **Pyrometers Based upon the Fusibility of Known Alloys.**—The pyrometer constructed by James Prinsep,[*] in 1827, is based upon this principle, and it was made use of by Plattner[†] for the determination of the fusion points of metallurgical products, and also by Tunner[‡] to determine the temperature in different levels of iron blast furnaces. Alloys are produced from various metals, the exact fusion points of which are known. These points may be calculated from the following formula:—

$$x = As + Bs',$$

in which $x$ expresses the fusion point of the alloy, containing in one part A parts of a metal fusible at $s$ degree, and B parts of a metal fusible at $s'$ degrees. When small quantities of alloys of various known fusion points are exposed on an iron or clay plate to higher temperature for a certain time, part of the alloys will melt, and others will not, thus allowing the temperature to be estimated.

This pyrometer is simple, of easy application, and yields tolerably exact results.

Violette[||] applied a similar method for the determination of the temperatures at which the carbonisation of wood takes place. He employed a mercury pyrometer up to 350° C., and for higher degrees small pieces of antimony, copper, silver, steel, iron, and platinum; the latter metal he melted in a furnace of special construction.[§]

These kinds of pyrometer may be also used for ascertaining the temperature of hot blast.[¶]

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[*] POGG., Ann., xiv., 525.

[†] PLATTNER, über die Bestimmung der Schmelzpuncte mehrerer Hüttenproducte and der Hitzgrade, bei denen sich verschiedene Silicate bilden. Beilage zu MERBACH's Anwendung der erwärmten Gebläseluft: Freiberg, 1840, p. 288.

[‡] LEOB., Jahrb., ix., Bd. 1860, p. 290. B. u. h. *Ztg.*, 1860, p. 208.

[||] DINGL., Polyt. Journ., Bd. cxxiii., 117.

[§] Ibid., cxxvii., 114. B. u. h. *Ztg.*, 1853, p. 537.

[¶] SCHEERER's Metallurgie, i., 490. Neuer Schauplatz der Bergwerkskunde, xv., 54.

The exactitude of these methods depends on the correct determination of the fusion points of the alloys employed. According to Kopp,[*] the results of Plattner's formula are incorrect.

Appolt Bros.,[†] determined the fusion points of alloys more correctly by the following method:—A wrought-iron plate weighing 2 kilos., and being 0·2 metre long, 0·1 metre broad, and from 15 to 20 millimetres thick, is provided with one or two semi-spheroidal depressions, and heated to such a degree that, after removing it from the fire, two alloys to be determined will fuse perfectly when placed in the depressions. The latter are covered with a piece of charcoal in order to prevent oxidation. At the moment when the grains of metal commence solidifying, the iron plate is immersed in a wooden vessel, which contains a measured quantity of water (about 12 litres) of 10° or 12° C. The water is then well stirred with the plate, the temperature of the warmed water is determined, and the iron plate weighed. The fusion point, T, may then be calculated from the formula—

$$T = \frac{P}{p.c}\,(t'-t) + t,$$

in which P represents the weight of the water employed, $c$ the specific heat of iron in comparison to that of water, which is considered equal to 1; when, according to Regnault, the specific heat of iron will be = 0·125; $t$, the temperature of the water before immersing the iron plate, $t'$ after immersing, and $p$ the weight of the iron plate.

If, for instance, P = 12,000 grammes, $p$ = 2000 grammes, $c$ = 0·125, $t$ = 10° C., and $t$ = 32° C., it will follow:—

$$T = \frac{12{,}000}{2000 \times 0{\cdot}125}\,(32-10) + 32 = 1088^\circ \text{ C.}$$

For the purpose of measuring the temperature on the walls of the compartments into which their coke furnaces are divided, Messrs. Appolt determined, by that method, the fusion points of a number of alloys, of which the following are some examples:—

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[*] Kopp, Modification der Mittleren Eigenschaft: Frankfort, 1841.

[†] B. u. h. Ztg., 1856, p. 165, No. 20.

1 part of tin with 4 parts of copper = 1050° C.
1 ,, ,, 5 ,, ,, = 1100° ,,
1 ,, ,, 6 ,, ,, = 1130° ,,
1 ,, ,, 8 ,, ,, = 1160° ,,
1 ,, ,, 12 ,, ,, = 1230° ,,
1 ,, ,, 20 ,, ,, = 1300° ,,

These alloys are employed in such a manner that grains of the size of a pea are placed into hemispherical depressions at the end of an iron bar; they are then covered with an iron plate, and the bar is pushed into those places, the temperature of which is to be determined. After some time it is again removed, when some alloys will have been fused, and others not, thus showing the temperature of the different places.

*c.* **Electric Pyrometer.**—This kind of pyrometer has been suggested by Steinheil and Pouillet, and also by Becquerel, whose pyrometer is described in Mitchell's "Assaying." In measuring the degree of temperature, these pyrometers make use of the thermo-electricity evolved by heating various kinds of metals which are in contact with each other, or by heating two platinum wires of different diameters; the current of thermo-electricity acts upon a magnetic needle. These pyrometers are said to give very trustworthy results.

*d.* **Hydro-Pyrometers.**—These were first employed by Clement-Desormes,* and by Schwarz,† afterwards by Appolt, Wilson, and Byström. Fabre du Faur used these pyrometers for the determination of the temperature of puddling and re-heating furnaces heated with gas.‡ Wilson's and Byström's apparatus are described in Mitchell's "Assaying."

The following table shows the heating power of fuel, and the degrees of temperature of various metals and metallurgical products for fusion, &c.

| | Absolute Heating-power. | Specific Heating-power. | Pyrometric Heating-power. Temperature for Fusion, &c. °C. |
|---|---|---|---|
| Tin fuses . . . . . . . | — | — | 222·5—267 |
| Bismuth fuses . . . . | — | — | 241—265 |
| Lead fuses . . . . . | — | — | 322—334 |
| Zinc fuses . . . . . . | — | — | 411 |

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* Dingl., Polyt. Journ., Bd. xxxiii., 145.
† Pogg., Ann., xiv., 530.
‡ Oesterr. Ztschr., 1859, p. 148.

| | Absolute Heating-power. | Specific Heating-power. | Pyrometric Heating-power. Temperature for Fusion &c. °C. |
|---|---|---|---|
| Antimony fuses | — | — | 512 |
| Commencing red heat | — | — | 525 |
| Dark red heat | — | — | 700 |
| Commencing cherry-red heat | — | — | 800 |
| Strong cherry-red heat | — | — | 900 |
| Red litharge fuses | — | — | 954 |
| Full cherry-red heat | — | — | 1000 |
| Copper matt fuses | — | — | 1002 |
| Silver fuses | — | — | 1023 |
| Lead matt fuses | — | — | 1027 |
| Black copper fuses | — | — | 1027 |
| Raw matt fuses | — | — | 1047 |
| Lead speiss fuses | — | — | 1062 |
| Dark yellow heat | — | — | 1100 |
| Gold fuses | — | — | 1102 |
| Copper fuses | — | — | 1173 |
| Light glowing | — | — | 1200 |
| White heat | — | — | 1300 |
| Lead and lead matt slag fuse | — | — | 1317—1300 |
| Raw slag fuses | — | — | 1330—1360 |
| Black copper slag fuses | — | — | 1345 |
| Iron blast furnaces cinder fuses | — | — | 1390—1430 |
| Strong white heat | — | — | 1400 |
| Gaseous fuel | 0·08—0·205 | 0·0001—0·00027 | 1450—1850 |
| Bright white heat | — | — | 1500—1600 |
| Cast-iron | — | — | 1500—1700 |
| Wood | 0·36—0·47 | 0·14—028 | 1575—1750 |
| Turf | 0·37—0·65 | — | 1575—2000 |
| Steel fuses | — | — | 1700—1900 |
| Brown coal | 0·43—0·85 | — | 1800—2200 |
| Wrought-iron fuses | — | — | 1900—2100 |
| Mineral coal containing 5 per cent of hygroscopic moisture and 5 per cent of ash | 0·79—0·96 | 1·06—1·14 | 2200—2350 |
| Turf coal | 0·33—0·85 | — | 2050—2350 |
| Charcoal | 0·64—0·97 | 0·10—0·20 | 2100—2450 |
| Coke containing not more than 5 per cent of ash | 0·84—0·97 | 0·33—0·46 | 2350—2450 |
| Platinum fuses | — | — | 2534 |

The temperature of the charcoal iron blast furnace at Wasseralfingen was determined to be 2774° C., that of the puddling furnace, heated with gas, 2692° C., and that of the re-heating furnace, heated with gas, 3100° C.

The temperature of a porcelain furnace, when melting the glaze, is, according to Elsner, about 2000° C.

## I. COMPACT FUEL.

### A. Wood.*

1. Wood is composed of fibrous matter, which constitutes the vascular system of the wood, and amounts to about 96 per cent of perfectly dry wood. The fibrous matter of all kinds of wood has always the same composition:—

| | |
|---|---|
| C | 52·65 |
| H | 5·25 |
| O | 42·10 |

or nearly equal parts of carbon and water.

According to Violette, the components are not uniformly distributed in one and the same tree; the fibres of the roots and leaves contain 5 per cent less carbon than the wood of the trunk; on the other hand, the bark of the branches and roots contains 5 per cent more carbon than that of the trunk or body. The real wood in trunk, branches, and roots is of the same composition. A different arrangement of the wood fibre modifies the weight, inflammability, heating power, &c., of the wood. According to the state of porosity, on which the specific weight† depends, the different kinds of wood are classified as hard, half-hard, and soft wood. The hard wood comprises oak, red beech, white beech, birch, elm, box, nut, plum, pear, chesnut, ash, juniper, and cornel trees; the half-hard kinds of wood are maple, acacia, service tree (*Sorbus aucuparia*), apple, alder, mulberry, horse-chesnut, larch-fir, and Scotch-fir; the soft kinds of wood are fir, silver-leaved fir, (*Pinus abies*), pine wood, lime, aspen, poplar, and willow. Most kinds of wood have less specific gravity than water, although, on the other hand, the specific gravity of the compact parts of wood is greater by nearly one-half. The specific gravity of the fibres of wood is 1·5.

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* Klein, Beiträge zur Physik. Technol. Kenntniss des Holzes, 1838.

† Karmarsch in Erdm. J. f. pr. Chem., ii. 207; vii., 45. Dingl., Polyt. Journ., x., 78. Knoblauch, über den Zusammenhang zwischen den physik., Eigenschaften und den Structurverhältnissen des Holzes. Polyt. Centr., 1859, No. 5, p. 312.

The hard kinds of wood burn with flame for some time on the surface only, whilst the interior mass of the wood undergoes the process of carbonisation. As soon as the carbonisation is completed the flame disappears, and the remaining compact charcoal burns without flame, forming carbonic acid. Soft wood produces flame during the whole period of combustion, and but little coal remains. The resinous kinds of fir wood yield the longest flame. The application of the different kinds of wood to various purposes is based upon this behaviour, according to whether a flaming or glowing fire is required. The inflammability of beech wood can only be raised by a much longer preparation, which consists in drying it in kilns to that degree which resinous fir wood possesses when only part of its hygroscopic water has been removed; it was considered impracticable to use beech wood in puddling and re-heating furnaces, before the use of gaseous fuel was introduced.

2. Wood contains sap or juice of variable composition, to the amount of about 4 per cent in air-dried wood. The different nature of wood (pine wood and leaved wood) is partly dependent on the organic components.

The inorganic substances in wood, on combustion, form ash;* these substances are soluble carbonates, sulphates, and chlorides, and a small quantity of alkaline silicates and phosphates, as well as lime, magnesia, peroxide of iron, and peroxide of manganese, combined with carbonic acid, phosphoric acid, silica, and sulphuric acid, thus forming salts which are insoluble in water. The soluble components of the ash are contained in the smallest quantity in the body of the tree, and they increase in the younger parts of the tree to such a degree that the fruit contains nearly eight times as large a proportion as the body.

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* SPRENGEL, über die feuerfesten Bestandtheile des Holzes. SCHWEIG-SEIDEL, Journ. i., 183. ERDM., Journ., f. ök. Chem, xiii., 382. FRESENIUS and WILL, über den Aschengehalt der Vegetabilien, Pharm. Centr., 1844, p. 453. BERTHIER, Untersuchung der Asche von verschiedenen Holzarten in KARST. Arch., 1 R., xiv., 419. BERTHIER, Met. Analyt. Chem., i., 136.

The amount of ash in wood varies between 0·2 and 5 per cent, according to the kind of wood, and the nature of the ground upon which the tree is grown; it usually amounts to 1 per cent. According to Chevandier,* wood of young trees yields, on an average, 1·23 per cent of ash, the wood of the body of the tree 1·34 per cent, that of the branches 1·54 per cent, and that of the twigs 2·27 per cent.

According to Karsten, Berthier, and Chevandier, pine wood yields from 0·15 to 0·83 per cent of ash; fir from 0·15 to 1·24 per cent; oak from 0·15 to 2·5; and beech from 0·4 to 0·86 per cent. The juice plays a part in the combustion, and especially influences the inflammability; for this reason floated wood loses in quality. According to Werneck, 1 cubic foot of wood, on floating, loses as much as 1 lb., which, however, is doubtful.† Experiments made in the Lower Hartz in 1853, showed that fir sixty years old, which had floated for three and a half weeks after it had been hewn down four months, lost 6·25 per cent in volume, and 1·08 per cent further on being dried again in the open air. A quantity of wood, amounting to 1478½ lbs., lost, in the operation of floating and drying again, 22·8 per cent of its weight. On the other hand, wood which had not been floated lost nothing in volume, and 17·5 per cent in weight, on being made air dry. 1478½ lbs. of floated wood evaporated 2910 lbs. of water, or 1 lb. of such wood evaporated 1·969 lbs. of water; and 1478½ lbs. of wood that had not been floated, evaporated 3194 lbs. of water, that is 1 lb. evaporated 2·169 lbs. of water; 100 lbs. of floated wood are therefore equal, in effect, to 90·77 lbs. of wood that has not been floated, or, in other words, the wood lost by the operation of floating mechanically and by lixiviation 9·23 per cent of its heating power. In dry air, as well as in water, wood may be preserved for a long time, but it gradually becomes decomposed by combining with oxygen, and by emitting carbonic acid, if it is alternately exposed to the influence of air, water, and light.

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* Liebig's Jahresbericht, 1847-48, p. 1098.

† Dingl., Polyt. Journ., cxv., 155.

3. Wood always contains hygroscopic water,[*] which, in freshly hewn wood, amounts to from 20 to 50 per cent, and, in perfectly air-dried wood, to from 18 to 20 per cent. The hard kinds of wood, in the autumn and winter seasons contain, on an average, 35 per cent of water, and the soft kinds 45 per cent; both kinds contain 5 per cent more in the spring and summer. Common fire-wood, on being dried in the air, still contains from 20 to 25 per cent of water. The wood, before being used, is usually dried in the air for one or two years, when it may be used for those metallurgical processes which do not require a temperature above 1000 or 1600° C. If the production of a higher temperature (from 1700 to 1900° C.) is intended, the wood requires to be dried artificially. This may be effected either by storing the wood in the neighbourhood of furnaces, on their roofs, or on scaffolds erected above the furnaces for the purpose, or special drying apparatus may be employed, which, if possible, are heated to about 100° C. by means of the waste gases of other fire-places.[†] Strongly dried wood re-absorbs in one year from 8 to 10 per cent of water.

**Composition of Wood.**—The composition of air-dried wood may be considered to be from 18 to 20 per cent of hygroscopic water, and 80 to 82 per cent of woody substance; or, as the latter contains one-half by weight of carbon and the other half of oxygen and hydrogen in the proportion required for the formation of water, wood is composed of 40 per cent of carbon, ash included, 40 per cent of chemically combined water, and 20 per cent of hygroscopic water. On heating wood up to 120° C., the hygroscopic water will escape, and dried wood remains, containing 50 per cent of carbon, inclusive of 1 per cent of ash and 50 per cent of chemically combined water.

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[*] SCHUBLER und NEUFFER in ERDM'S Journ. f. ök. u. techn. Chem., vii., 35. CHEVANTIER, Polyt. Centr., 1847, p. 292.

[†] ERDM., J. f. ök. techn. Chem., xvi., 275. ERDM., J. f. pr. Chem., xxiv., 116. KARST., Arch., 1 R., iii., 139, 189; xvi., 235. Bgwkfd., iii., 27, 111; iv., 81, 485; xii., 639. B. u. h. Ztg., 1843, pp. 58, 444. TUNNER'S Jahrb., iii., 407. Ann. d. min., iii. sér., tom. ix., 449; xiii., 217; xviii., 647. HARTM., über d. Betrieb der Hohöfen mit erhitzter Luft., 4 Hft., p. 76, Taf. 3—5. Neuer Schauplatz der Bergwerkskunde, xiv., 34, Taf. 1, Figs. 4—10. LE PLAY, Grundsätze, welche die Eisenhüttenwerke mit Holzkohlen und die Waldbesitzer befolgen müssen, um den Kampf gegen die Hütten mit Steinkohlenbetrieb erfolgreich zu bestchen, deutch. V. HARTM.: Freiberg, 1854, p. 172.

According to Schödler and Peterson, different kinds of wood, being finely rasped and dried at 100° C., showed the following composition :—

| | | | | Required for the Formation of Water. | Excess of |
|---|---|---|---|---|---|
| | C. | H. | O. | H. | H. |
| Beech . . . . . | 48·53 | 6·30 | 45·17 | 5·64 | 0·66 |
| Birch . . . . . | 48·60 | 6·37 | 45·02 | 5·63 | 0·64 |
| Fir . . . . . . | 49·95 | 6·41 | 43·65 | 5·46 | 0·95 |
| Pine . . . . . | 49·59 | 6·38 | 44·02 | 5·50 | 0·88 |
| Scotch fir (*Pinus sylvestris*) . . | 49·94 | 6·25 | 43·81 | 5·48 | 0·77 |

**Heating Power of Wood.**—The heating power* and specific gravity of various kinds of wood are shown in the following table :—

| | Heating Power. C = 1. | | | 1 part by weight of Wood reduced *Lead* (C = 34). | 1 part by weight of Wood heats *Water* from 0° up to 100° C. | Specific Gravity of the Air-dried Wood. |
|---|---|---|---|---|---|---|
| | Absol. | Specif. | Pyrom. | | | |
| Air-dried wood containing 20 per cent hygroscopic moisture .. .. .. | 0·36 | — | 1575° C. | — | 35 | — |
| Artificially - dried wood containing 10 per cent of hygroscopic water.. | 0·41 | — | 1675° C. | — | — | — |
| Kiln-dried wood .. | 0·47 | — | 1750° C. | — | — | — |
| White beech .. .. | — | 0·28 | — | 12·50 | 31 | 0·770 |
| Holm oak .. .. | — | 0·26 | — | 14·05 | 24—30 | 0·708 |
| Ash .. .. .. .. | — | 0·24 | — | 14·50 | 30—35 | 0·670 |
| Maple .. .. .. | — | 0·23 | — | 14·16 | 36 | 0·645 |
| Red beech .. .. | — | 0·24 | — | 14·00 | 33—36 | 0·591 |
| Scotch fir .. .. | — | 0·20 | — | 13·27 | — | 0·550 |
| Willow .. .. .. | — | 0·19 | — | 13·10 | — | 0·487 |
| Pine.. .. .. .. | — | 0·19 | — | 13·38 | 28—37 | 0·472 |
| Lime.. .. .. .. | — | 0·18 | — | 14·48 | 34—40 | 0·439 |
| Black poplar .. .. | — | 0·14 | — | 13·04 | 34—37 | 0·387 |
| Birch .. .. .. | — | 0·23 | — | 14·08 | — | 0·627 |
| Fir .. .. .. .. | — | 0·19 | — | 13·86 | — | 0·481 |

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* PETOT's Ermittelungen in Berth. metal. anal. Chem., deutch v. HARTM. i., 240.

This table shows that the absolute heating power of the various kinds of wood stands nearly on an equality; the specific heating power of those kinds of wood that contain an equal amount of water stands, therefore, in the same proportion as their specific gravities. The absolute heating power of different sorts of air-dried wood may be considered equal to 13·95 parts in weight of lead, or to 3200 caloric units, or to 0·41 per cent of pure carbon.

**Value of Wood.**—As wood in most cases is bought by volume, its specific gravity immediately indicates the relative value* of it, when the size and shape of the pieces and the manner in which they are piled up into heaps is taken into consideration. The weight of a certain volume, under equal circumstances, is the greater the thicker the pieces of wood are, and the higher their specific gravity. In buying wood, the interstices between the pieces have, therefore, to be taken into consideration, the amount of which usually stands in a fixed proportion to the total volume of the heap. Knapp, for instance, calculates that a heap of wood 6 feet long and 6 feet high contains one-fifth of its volume of empty interstices. Fire-wood made of the stumps and roots contains twice as many interstices as log-wood (fire-wood in large pieces), and billet wood four times as many. 100 cubic feet of wood contain 70 of log-wood, 60 of billet wood, 50 of wood made of stumps and roots, and 25 of brush-wood. According to Landet, the interstices amount to one-eighth, one-sixth, and even to one-fifth of the total volume. Marcus Bull asserts that a heap of wood contains only 56 per cent of compact wood, while Karmarsch declares the amount to be two-thirds. In some Austrian salt works 108 cubic feet of piled-up beech wood are estimated to contain 78·15 cubic feet of solid wood (1 Austrian cubic foot equal to 37·69 Austrian lbs.), and 108 cubic feet of fire-wood in large pieces (log-wood) 77·41 cubic feet (1 cubic foot equal to 26·41 lbs.) At the Upper Hartz, it has been ascertained that 80 cubic feet of piled-up fire-wood contained 50 cubic feet of solid wood, and 80 cubic feet of piled-up wood of leaf-bearing trees in larger pieces 48 cubic feet. One Hanoverian cubic foot of air-dried fir-wood weighs, on an average, 26 lbs., or 13 kilos.

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* Erdm. Journ. f. pr. Chem., viii., 321; xvii., 63. Polyt. Centr., 1851, p. 1430; 1854, p. 530. Hartig, Brennwerth verschiedener Holz- und Torfarten Braunschweig, 1855. Oesterr. Ztschr., 1857, p. 66.

**Properties of Wood.**—Wood is superior to most kinds of mineral fuel, on account of its uniform composition and its small amount (½ per cent) of mineral admixtures, and these even are not injurious; wood, therefore, as well as charcoal, is greatly to be preferred for application to iron blast furnaces. Green wood, on the other hand, has great disadvantages; its woody substance produces a lower temperature than mineral fuel, although the latter is rendered impure by the presence of a large proportion of earthy admixtures; besides, the hygroscopic water contained in wood causes the quantity of heat produced to be non-uniform. In order to obtain the full effect of wood, it is requisite to remove its hygroscopic water by drying in the open air (page 297), or by artificially drying (page 304).

It is best to fell wood in the month of March, and to keep it piled up in the open air or under airy sheds for a long time, to prevent it from becoming mouldy. Good wood must be sound, full grown, and not decayed from age, nor damaged by caterpillars, nor worm-eaten.

**Application of Wood.**—Wood, in more or less thin branches, or in large pieces is frequently employed in roasting processes and in reverberatory furnaces, such as puddling and cupelling furnaces, but not often in blast furnaces (in iron blast furnaces,[*] for instance), or in the American lead hearth.[†] Wood, chiefly waste, pine nuts, twigs, &c., is also used for the production of combustible gases.[‡] Pine nuts are sometimes directly employed in the roasting of iron ore, or they are used together with charcoal in blast furnace processes.

[*] ERDM., J. f. ök. u. techn. Chem., xii., 337; xiv., 416; xvi., 275; xvii., 471. ERDM., J. f. pr. Chem., ii., 337; vi., 231. DINGL., Polyt. Journ., lxi., 480; lxiv., 235, 397; lxviii., 441; lxix., 142; lxxxviii., 264; xc., 28. Bgwkfd., i., 356; ii., 501; iv., 485; v., 193; viii., 375. KARST., Arch., 2 R., xii., 408; xxv., 261. B. u. h. Ztg., 1842, p. 324; 1843, pp. 441, 545; 1852, p. 481; 1855, pp. 153, 170; 1859, pp. 282, 440. TUNNER'S Jahrb., 1854, p. 210. Oesterr. Ztschr., 1853, pp. 62, 197.

[†] B. u. h. Ztg., 1854, p. 22.

[‡] Ibid., 1849, No. 6; 1851, p. 469; 1852, p. 610.

**Practical Experiences.**—In the use of wood the following practical results have been obtained :—

1. The Polytechnic Society of Hesse has determined that, in heating boilers, one pound of beech wood hewn two years previously will evaporate 2·075 lbs. of water of 0°. According to Berthier, good fire-wood by theory ought to evaporate 4½ or 5 lbs. of water of 0°; in practice, however, in salt works, for instance, only 2½ or 3 lbs., or, at the very highest, 3½ lbs., are evaporated. In the salt works of the Lower Hartz, 1 lb. of wood evaporates from 2·495 to 2·838 lbs. of water. According to Karsten, in making salt, 1·6 parts by weight of wood have the same effect as 1 part of mineral coal or 2·5 parts of turf, and 1 part by volume of coal has an equal effect with 4 parts of wood or turf; in the production of higher temperatures, in reverberatory furnaces, for instance, 1 part by weight of coal replaces 2·6 parts of wood, and 1 volume of coal 7 volumes of wood. One part by weight of wood evaporates 3 or 3½ parts by weight of water at the common temperature of the air, supposing the fire-place to be judiciously constructed.

2. In the salt works at Artern, it was determined that, in the process of seething, 1 klafter of oak wood, equal to 108 cubic feet, had the same effect as—

1·04599 klafter of half oak and half fir-wood.
1·12469 „ floated wood.
1·14949 „ fir-wood.
8·49839 three score bundles of brush-wood, 30·625 cubic feet each.
3·49839 tons (Pruss.) mineral coal of Löbejüne, 12,288 cubic inches each.
4·19996 tons (Pruss.) mineral coal of Wettin, 12,288 cubic inches each.
13·73767 tons (Pruss.) brown coal of Riestadt in lumps.
18·73799 „ dry „ Voigtstadt „
18·96319 „ mixed „ „ „
19·01323 „ common „ „ „

3. According to Karmarsch,* 1000 cubic feet of pine wood have the same effect as 650 beech, 680 birch, and 900 alder;

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* Mittheilungen des Gew. Ver. f. d. Königr. Hanover, 1835, p. 314; 1853, pp. 213, 277.

or 1 klafter of pine wood of 2600 lbs. in weight, and 144 cubic feet in size, which, after deducting one-third of supposed interstices, contains 100 cubic feet of solid wood, will have the same effect as two-thirds klafter of beech or birch, or seven-eighths klafter of fir and one klafter of alder; 1 lb. of wood evaporates, on an average, 3·5356 lbs. of water.

4. According to Landet,* the value of fuel bought by volume corresponds to the product of the absolute heating power of fuel into the weight of a certain volume.

These two factors have the following value with various kinds of fuel:—

| | Absolute Heating Power. | Weight of 1 cubic metre in kilos. |
|---|---|---|
| Holm oak (wood in large pieces, or logs) | 10000 | 380 |
| Red beech (logs) | 9941 | 380 |
| Oak, both varieties in mixture (logs) | 9763 | 371 |
| White beech (logs) | 9490 | 370 |
| Oak (logs) | 9448 | 359 |
| White beech (pieces and stumps in mixture | 9392 | 338 |
| Birch (logs) | 9260 | 381 |
| Birch (pieces and stumps, &c., in mixture) | 9224 | 332 |
| Birch (stumps) | 8836 | 318 |
| Pine (stumps) | 8587 | 312 |
| Oak (both varieties in mixture) | 8342 | 317 |
| Red beech (stumps) | 8214 | 314 |
| Alder (log-wood) | 8127 | 293 |
| Alder (pieces and stumps in mixture) | 8070 | 291 |
| White beech (stumps) | 8030 | 313 |
| Red beech (branches) | 7953 | 304 |
| Pine (branches) | 7898 | 287 |
| Alder (stumps) | 7849 | 283 |
| Pine (stumps) | 7808 | 283 |
| Pine (branches) | 7752 | 281 |
| White beech (branches) | 7644 | 298 |
| Pine (logs) | 7624 | 377 |
| Willow (pieces and stumps in mixture) | 7584 | 285 |
| Birch (branches) | 7473 | 269 |
| Willow (branches) | 7344 | 276 |
| Aspen (pieces and stumps) | 7290 | 273 |
| Oak (both varieties in mixture) | 7288 | 277 |

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* Polyt. Centr., 1854, p. 531.

| | Absolute Heating Power. | Weight of 1 cubic metre in kilos. |
|---|---|---|
| Pine (logs) | 7064 | 256 |
| Charcoal | 7000 | — |
| Turf dried at 100° C. | 4800 | — |
| Turf containing 20 per cent of water | 3600 | — |
| Turf charcoal | 5800 | — |
| Mineral coal of medium quality | 7500 | — |
| „ „ „ „ containing 15 per cent of ash | 6000 | — |
| Wood dried at 100° C. | 3600 | — |

In practice, the effect of wood is not always proportionate with its heating power; as, for instance, on heating a boiler for the evaporation of the water contained in it, those kinds of wood will be most advantageous that produce the most flame.

With regard to this property, the various kinds of wood stand in the following order:—

| | |
|---|---|
| Mulberry | 100 |
| Fir | 89 |
| Red beech and ash | 87 |
| White beech | 85 |
| Lote | 82 |
| Holm oak | 75 |
| Larch and elm | 72 |
| Oak | 70 |
| Birch | 68 |
| Pine | 63 |
| Acacia | 59 |
| Lime | 55 |
| Aspen | 51 |
| Alder | 46 |
| Willow | 40 |
| Italian poplar | 39 |

Based upon these figures, the value of the various kinds of fuel may be determined, as is shown in the following example:—

What is the value of red beech wood (branches) if the price of 1 cubic metre of oak wood amounts to 7 francs?

As the ratio of the heating power of oak is 9448, and that of red beech 7953, and as the weights of 1 cubic metre of both kinds of wood are 359 and 304 respectively, the value of both kinds of wood stand in the following proportion:—

$$9448 \times 359 : 7953 \times 304 = 3391832 : 2427712,$$

and 1 cubic metre of beech wood will therefore have the value of

$$\frac{2427712 \times 7}{3391832} = 5 \text{ francs } 1 \text{ cent.}$$

5. According to Petot,* experience has determined that, on burning good dry wood and all the gases produced from it, a temperature of 1683° C. is produced if all the oxygen of the air of combustion is absorbed, and that a temperature of 960° C. results if only half of the oxygen is consumed; freshly hewn wood, under equal circumstances, yields temperatures of 1337° C. and 820° C. respectively; and wood that has been dried in the air for twelve months yields temperatures of 1534° C. and 909° C. respectively.

According to Scheerer, air-dried wood, on combustion, produces a temperature of 1750° C. at the very highest, whilst the pyrometric heating power of kiln-dried wood, which is cut into small pieces, amounts to from 1850 to 1950° C. Le Play states that pure woody substance yields a temperature of 1700° C., wood containing 40 per cent of water a temperature of 1380° C., and wood containing 82 per cent of water a temperature of 1120° C.

6. The power of radiation varies in wood, according to whether a larger or smaller quantity of wood is present. The radiant heat, with small pieces, amounts to the almost constant proportion of one-third of the quantity of heat which is carried away by the escaping gases, and to a quarter of the total quantity of heat produced; with charcoal and mineral coal the radiant heat amounts to half, and with turf and turf charcoal to five-twelfths.

7. Brix, by his very exact experiments,† has ascertained that the various kinds of wood evaporate the following

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* Berthier, met. Analyt. Chem., i., 240.

† Brix, Untersuchungen über die Heizkraft der wichtigsten Brennstoffe des Preuss. Staates: Berlin, 1853. Mittheil. des Gew. Ver. für das Königreich, Hanover, 1853, p. 207. Berggeist, Nos. 15, 68, de 1859.

quantities of water; the experiments were made on a large scale, and well constructed fire-places were employed:—

| | Amount of Water. | Amount of Ash of the | | Weight of 108 cubic feet in lbs. | 1 lb of Fuel converts into Steam of from 88° to 92° C. — lbs. of water of 0°. | |
|---|---|---|---|---|---|---|
| | | Green material. | Dry material. | | Green wood. | Dried wood. |
| | per cent. | per cent. | per cent. | | | |
| Old fir-wood .. .. | 16·1 | 1·92 | 2·29 | 2650 | 4·13 | 5·11 |
| Young ,, .. .. | 19·3 | 1·73 | 2·15 | 2500 | 3·62 | 4·77 |
| ,, ,, dry .. | 15·6 | 0·46 | 0·55 | 2500 | 3·69 | 4·55 |
| Alder .. .. .. .. | 14·7 | 0·95 | 1·11 | 2335 | 3·84 | 4·67 |
| Birch .. .. .. .. | 12·3 | 1·00 | 1·14 | 2780 | 3·72 | 4·39 |
| Oak.. .. .. .. .. | 18·7 | 1·13 | 1·39 | 3125 | 3·54 | 4·60 |
| Red beech, old .. | 22·2 | 1·43 | 1·84 | 3100 | 3·39 | 4·63 |
| ,, ,, young | 14·3 | 1·39 | 1·62 | 3100 | 3·49 | 4·25 |
| White beech .. .. | 12·5 | 2·17 | 2·48 | 3100 | 3·62 | 4·28 |

We have before observed that the quantity of ash is not uniform throughout the whole, or in all parts of a tree, and it appears that in old trees of the same kind the quantity of ashes is larger than in saplings. The following table refers to kiln-dried wood:*—

| Age. | Kind of Wood. | Part of the Tree. | Quantity of Ash per cent. |
|---|---|---|---|
| 120 years | oak | trunk | 2·43 |
| ,, ,, | ,, | branch | 2·03 |
| 70 ,, | ,, | ,, | 2·10 |
| 30 ,, | ,, | ,, | 1·45 |
| 70 ,, | beech | trunk | 0·86 |
| 120 ,, | ,, | branch | 1·93 |
| 75 ,, | ,, | ,, | 1·70 |
| 20 ,, | ,, | ,, (very young) | 1·50 |

As not only the quantity of ash, but its chemical composition, has a bearing on metallurgical operations, we insert two tables, one of which points out the most characteristic qualities, and the other shows the amount of potash present in the ash of various kinds of wood and plants:—

| Kinds of Wood. | Percentage of Ash | Silica. | Potash and Soda. | Carbonate of Lime. | Magnesia. |
|---|---|---|---|---|---|
| Beech (charcoal) | 3·3 | 6·8 | 64·1 | 42·6 | 7 |
| Oak . . . . | 2·5 | 4 | 67·6 | 54·8 | 6 |
| Pine (charcoal). | 10·24 | 6 | 83 | 42·3 | 10·5 |
| Wheat straw . | 4·4 | 11 | 50 | 5·8 | — |

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[*] OVERMANN's Treatise on Metallurgy: New York, 1865, p. 338.

| 1000 Parts of | Contain Potash. |
|---|---|
| Pine wood | 0·45 |
| Poplar „ | 0·75 |
| Beech „ | 1·45 |
| Oak „ | 1·53 |
| Willow„ | 2·85 |
| Maple „ | 3·90 |
| Wheat straw | 3·90 |
| Barley | 5·80 |
| Cornstalk | 17·50 |
| Wormwood | 73·00 |

8. Grobner,* on comparing the heating power of the principal kinds of wood, ascertained that 1 klafter of beech wood, in pieces 3 feet long, containing 78 cubic feet of solid wood, and weighing 30·5 cwts., produced the same effect as 1·3 klafter of pine wood, in pieces, or 13 cwts. of brown coal from Leoben and Pilsen, as 21 or 22 cwts. of turf from Upper Austria or Bavaria, and as 28 cwts. of turf from Moravia.

## CHARCOAL.

The carbonisation of wood† is intended to remove those constituents which absorb heat, and to concentrate the carbon, which possesses a great pyrometric heating power. The substances absorbing heat are the hygroscopic water and oxygen contained in the wood, which, on combustion, cause the formation of so much water that the temperature is decreased to a considerable degree.

The earliest method of *coaling wood*, as the manufacture of charcoal was, and still is called, is as follows:—A piece of ground is levelled at some convenient spot in the forest, which is termed the "hearth" or "earth." This spot should be near to the stores of cord wood, that the cost of transportation of it may be low, and that the waggons for the hauling of coal may easily approach. Above all things, the place where the hearth is to be, must be dry, and free from rock. When no convenient level spot can be found, one from 40 to 50 feet in diameter is made on a hill side. All stones and gravel must be removed, and the ground must be dry and fine, not sandy or loamy; it is best to locate a hearth in a somewhat gritty soil. When stones or gravel cannot be avoided in the selection of a spot, the ground must be dug up for 1 or 2 feet, and riddled to remove all coarse matter. If the ground is too rocky or damp, a layer of brush-wood, 1 or 2 feet in depth, is spread over it, and upon this a layer of soil of 1 foot in thickness is thrown, which forms the hearth. If the soil is too sandy, it may be mixed with sufficient dry loam to make it slightly adhesive. In the centre of the hearth, which may be made slightly convex, either a thick pole, or three sapling posts, 4 inches in thickness, and of the height which the heap is to be, are erected; this is generally from 12 to 15 feet, most commonly 12 feet. These posts are placed about 1 foot apart, and are held in position by short braces, bound together with switches. At the bottom, between these posts, which form a kind of chimney, some dry inflammable substance, such as brands from former fires, dry chips, or charcoal, is deposited, in fact, this chimney may be filled at least half its height, or nearly to the top, with any of these substances. Around this centre, the billets of wood are erected, the heaviest first, with the buts lowermost, so as to form a gradual slope towards the circumference.

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* Oesterr. *Ztschr.*, 1853, p. 246.

† Ure's Dictionary of Arts and Mines, vol. i., p. 684. V. Berg, Anleitung zum Verkohlen des Holzes, 2. Aufl.: Darmstadt, 1860. Meyer, Berechnung der Kohlenmeiler, 1833. Freitag, die Köhlerei, Wernigerode, 1831. Mayerhofer, über die Verkohlung mit Gebläseluft, B. u. h. *Ztg.*, ii., 20. Af Urr, Anleitung zur vortheilhaften Verkohlung des Holzes in stehenden und liegenden Meilern, Aus dem Schwedischen übersetzt v. Blumof: Giessen, 1820. Dingl., vii., 264; xxiv., 280; xxvii., 404; xxxviii., 463; lii., 320; lxi., 237; lxii., 387; lxviii., 209. Sächsische Köhlerei, Erdm., Journ. f. ök u. Techn. Chem., vii., 47; viii., 137; ix., 430. Italianische Methode, Ann. des Mines, 3 sér., xi., 351. Dietrich über Verkohlung des Holzes in stehenden Meilern, 1847. Klein, Desgl., 1836. Scheerer's Metal., i., 211. Plattner, Vorlesungen über allgem. Hüttenkunde, p. 61.

One of the most important objects in setting a pit, is to have as few and as small spaces as possible, and when these exist, to fill them with small branches and short billets of wood. The collier therefore needs an axe for trimming and chopping, as the wood is not often so cleanly trimmed by the choppers as to form close joints. When sufficient charcoal dust is at hand, it is an excellent plan to entirely fill the crevices.

between the billets with small charcoal; this increases the yield considerably, and affords a charcoal superior to that derived from the open setting. A little more labour is thus caused, but in the course of time it pays well. In all cases, the round, or bark side of the billet is turned outwards, and the split sides towards the centre. In setting the second tier of wood, particular attention must be paid to the joints at the ends of the billets, because it is there that it is most difficult to prevent spaces. If three tiers of wood are set, the upper one is more inclined than the lower, to secure the adhesion of the cover.

In Norway,* the wood around the centre poles is laid flat, and covered outside with slabs, to obtain the slope. This method can only be adopted in the neighbourhood of saw-mills, where slabs alone can be obtained. The covering may be made equally well with billets, but no other advantage than the saving of a little labour in setting the wood is obtained. Wood laid horizontally never does, nor ever can, afford as strong a coal as when placed upright, and where strong coal is required for blast furnaces, this mode of charring is not advantageous, although it is so for forging and similar operations, where weak coal does equally well, and, indeed, is preferable to hard coal.

In Southern Europe, the wood is frequently laid almost horizontal, or inclined gently towards the periphery of the heap; it is used, in this instance, in the form of round sticks.

When a round heap is formed, all the exterior spaces are nicely filled, and thatched with chips, small branches, small wood brands, or charcoal. The whole is then covered with a layer of damp leaves, which are gathered from the ground near the pit. These leaves, which serve to prevent the dropping in of dust, or earth cover, are now overlaid with earth. The best cover is formed from the earth where one or two brands have been made, and the earth is blackened and mixed to a certain extent with fine charcoal. At first only a slight layer of earth is put on, merely to cover and hold the leaves down, so that a gust of wind may not blow them off. If one centre pole has been applied, this is now withdrawn in order to form a chimney, and the combustibles at the very bottom and centre of the heap are ignited by dropping some burning coals from the top into the centre; this should be done in the morning, and when neither wind nor storm is apprehended. In order that the covering of the heap may not be disturbed, the ascent to the top is effected by means of steps made of a 6-inch sapling, or a slab. The fire thus applied must be carefully watched, that it may continue to burn slowly; it is nourished by air drawn in through several places, which are left uncovered at the bottom of the heap. When the fire is well established, which usually takes some five or six hours, the centre is entirely filled with brands; but no cover is yet put on the top, only some leaves are thrown over to prevent a strong draught. The collier now proceeds to secure the earth all round by adding some more; so that within the first twenty-four hours, the heap is entirely covered with dust, from 2 to 3 inches in thickness. In the centre part of the top, the cover is thin, so that smoke, or, in fact, only steam and invisible gases, may escape. At the bottom are small air holes, which are not closed until the pit begins to sink or settle at the top. When the operation is conducted properly, this occurs after sixty hours' firing; if it takes place sooner, there is something wrong. While the settling is going on, the earth becomes moist, and is easily flattened down by a shovel, but this must be done with caution. If the cover is too close, as it is particularly liable to become when it consists of green dust, it is in danger of being partially blown off by explosions within. During the two first days it is not advisable, therefore, to have the cover too close or too heavy. On the other hand, a thin cover always requires more attention than a heavy one, and it is particularly unsafe in squally weather, and under the care of inexperienced persons. Most of these difficulties may be avoided, by making a heavy cover at the commencement, with a free vent at the top, and means for a liberal access of fresh air at the foot of the heap.

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* OVERMANN's Treatise on Metallurgy: New York, 1865, p. 362.

When the top begins to settle, some dust is thrown into the centre of it, so as to draw the fire more to the exterior, and as it continues to settle, this operation is continued for at least two days longer, to prevent a strong heat. During this period, the greatest caution and watchfulness must be exercised day and night, particularly in stormy seasons, and with green or sandy earth for a cover. It will sometimes happen, in spite of every precaution, that a pit settles irregularly, although the settlement ought to be uniform from the centre towards the periphery. When the former occurs, it is regulated by increasing the covering at the low places, and diminishing it at the high spots, so as to draw the fire towards them. If, either in consequence of a new hearth, or from inattention, a part of the pit burns hollow, and threatens to sink suddenly, that portion must be quickly opened by removing the cover, and filled with charcoal, brands, or even charcoal dust, if nothing else is at hand. Some colliers are in the habit of filling these hollow places with fresh wood; this is useless, for fresh wood does not make charcoal, at least not of good quality, and it is the cause of wasting what is already formed—in fact, it injures the whole pit. It frequently happens that the centre burns down too deep before the wood sinks; it is then filled with coal, and kept full, until it sinks regularly and simultaneously, after which it is covered with dust.

In fair weather, and under good management, the aspects of the pit change about the third day. The smoke then begins to be dry, no cloud of vapours hovers over the apex, and the gases begin to smell of the distillation products. The pit may now be entirely covered, and no air-hole left. When the cover has been too thin, it is increased; all cracks and crevices are carefully stopped, and the pit driven on very slowly without vents to urge the fire. If all these things have been carefully attended to, the settling of the pit is uniform; it begins in the middle, and extends gradually towards the circumference. The pit assumes, at this period, the form of an inverted cone, and the fire draws gradually from the centre towards the edge of the heap. The smoke, or hot gases, always escape at the highest part, or at those places where the fire exists; from the other parts of the surface, which ought to be dead, none should issue.

A pit must be closely watched in good seasons for four days, and in stormy weather for from six to eight days; after that time the fire is well spread in the interior, and, as little air is required, all the air-holes around the base are closely stopped. Some vent-holes may be put below the natural vent, for all the wood is now well dried, and the charring may be completed as soon as possible. In four days more, all the wood will be charred; thus a pit may be burned in a week or ten days, unless in stormy or wet seasons, when it will require between ten days and three weeks. When the fire is drawn to the circumference, the heap is closely covered and left to cool slowly.

After the further lapse of twenty-four hours, the drawing of the coal is begun; this proceeds slowly. From 200 to 300 bushels are taken during the first day from a fresh pit; this may be gradually increased, so that a pit of 2000 or 2500 bushels will be drawn in a week. This operation is commenced at the circumference; a little dust is removed from a place, and about one bushel taken by means of a wooden rake; the earth is then carefully replaced to prevent the access of air to the interior of the pit, and another place is opened. A careless or too rapid drawing may set the pit on fire again, and cause a great loss of coal. When the process of charring has been well performed, the pit shows a gently rounded mound of about half the height of the original pit, although it is somewhat higher when hard wood has been charred. An irregular waving surface indicates either bad work or a bad hearth.

Hard close-grained woods are longer in coaling than soft open-grained woods.

These technical instructions, handed down in the forests for ages as secrets from father to son, amongst the collieries of every country in Europe, are the results of long practical experience, and strictly accord with the true principles on which the process is based.

To carbonise wood under a movable covering, the plan of "*meiler*" pit or heaps is very generally employed in Germany. The heaps containing the wood in horizontal layers are called lying *meiler*; they are shown in Fig. 61. Heaps in which the wood is placed in nearly vertical layers, as shown in Figs. 62 and 63, are called standing *meiler*.

FIG. 61.

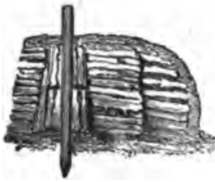


FIG. 62.

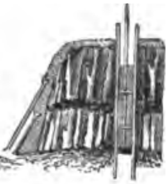
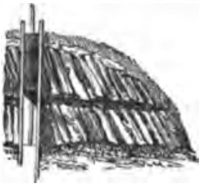


FIG. 63.



The success of the burning of the heap or pit is influenced by the direction of the billets,* for the fresh air which is drawn in at the foot will naturally follow this direction, or pass through the spaces between the billets, which, when properly set, make the strongest and most coal. The principal object in charring wood must be to conduct the fresh air over it, and not over the hot coal. If we kindle one end of a bundle of sticks and hold it so as to turn the flame downward, we do not obtain any coal. After the volatile substances are expelled, the hot charred wood is rapidly consumed, and ashes only remain. Thus the hot gases generated in the burning coal pass through the wood, dry it too fast, and convert it into small disconnected fibres, as if crushed by a hammer, such wood, cannot, of course, form any other than small coal, and very little of that. If we turn the flame of the faggot of wood upwards, the result is quite different, for the air, in passing through the spaces between the sticks, will absorb the moisture gradually, and dry the wood slowly. On arriving at the flame, it will find sufficient carburetted hydrogen to combine with, and consequently will not absorb much carbon, provided no excess of air is admitted, so as to furnish free oxygen. This mode will not, however, produce the largest quantity of coal; for if the coal above the flame is still red-hot, which, of course, cannot be prevented, the carbonic acid formed in contact with the volatile substances will absorb more carbon and form carbonic oxide, which is recognised by the blue colour at the extreme end of the flame. This blue flame is often observed in *meilers* when the cover is too light, and when there is too much heat in the coal. It invariably causes great loss, however good the coal may be. A strong cover to keep the fire down is the only means of preventing these occurrences.

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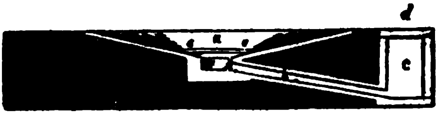
* OVERMANN'S Treatise on Metallurgy: New York, 1865, p. 357.

The perfectly vertical position of the billets with the fire at the top is, therefore, the most perfect manner of setting a pit, provided the access of air can be so regulated that only a sufficient quantity is uniformly drawn down. In order, however, to render the operation as perfect as possible, the billets are set in an inclined position.

In districts* where the wood can be transported into one place by means of rivers or mountain slides, a dry flat space, screened from storms and floods, must be selected; this may be walled round, having a slight declivity made in the ground towards the centre, as is shown in Fig. 64. Into this space the tarry acid will partially fall, and may be conducted outwards through a covered gutter beneath into a covered tank. The mouth of the tank must be shut during the coaling with an iron or stone slab, luted with clay. A square iron plate is placed over the inner orifice of the gutter to prevent its being choked with coal ashes. Fig. 64 represents a walled meiler station; *a*, the station; *b*, the gutter; *c*, the tank, which is covered with the slab, *d*; *e*, a slab which serves to keep the gutter clear of coals. The cover of the heaps is formed of earth, sand, ashes, or any other matter that may be most readily found in the woods. They should be kindled in the centre. The time required for charring a heap is from six days to a month, according to its

FIG. 64.



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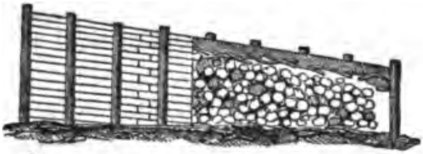
* URE's Dictionary of Arts and Mines, vol. i., p. 685.

size, hard wood requiring longer, and the slower the process, the better, generally speaking, is the quality of the product, and the greater its quantity.

The charring of wood in mounds* (*Haufen or liegende Werke*) differs from that in the *meiler*, because the wood in the *haufen* is successively charred, and the charcoal raked out little by little. The haufen is represented in Figs. 65 and 66. The product is said to be greater in this way, and also of better quality, which, however, is doubtful. Uncleft billets 6 or 8 feet long, being laid over each other, are covered with ashes and then carbonised. The station is sometimes horizontal and sometimes made to slope. The length may be 24 feet, the breadth 8 feet, and the wood is laid crosswise. Piles are set perpendicularly to support a roof made of boughs and leaves covered with ashes. Pipes, which serve to catch and carry off some of the liquid, are occasionally laid within the upper part of the mounds.

FIG. 65.



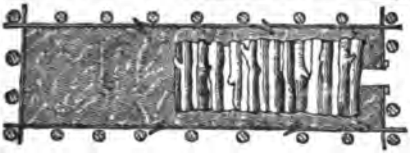


FIG. 66.

**Charring in Ovens.**—This mode of charring, as employed in America, is described by Overmann† thus:—In order to avoid keeping large stores of charcoal, and to obtain it dry and fresh, to save labour in particular cases, and to be less subject to the faults of inferior workmen, the charring in ovens or kilns is resorted to. Generally speaking, the advantages of ovens over heaps or pits are not so great as is often supposed, and, as a rule, we may assert that no charcoal made under an immovable cover is so strong as that made under a movable one. The only real advantage of the oven arises from its being less subject to the changes of the atmosphere than the pit. The best kind of char oven, and that which is most generally in use in America, is of a long prismatic form; the floor and rough walls of the oven are of common red brick, the interior of the side walls and the arched roof are lined with fire-brick. Such an oven is 40 feet long, 15 feet wide, and 15 feet high, in the clear, and will contain about sixty cords of wood. The oven is bound with wood and covered with a roof, which is a necessary appendage, as it protects the walls against moisture, which is particularly hurtful to the arch, and consequently to the coal. The floor is well paved with hard common bricks, set edgewise, below these another layer of bricks or stones is laid upon a plank floor, which rests upon the cross timbers or binders. The mode of binding requires no further explanation; it may be added, however, that it is necessary to use young and sound timber for this purpose. The bricks are laid in fire-clay mortar, in preference to lime mortar, because the latter is soon destroyed by the acetic acid which is liberated by the wood. This clay mortar ought not to be too fat, and it is advisable to use a little salt in it; this causes it to dry harder, and bind more strongly. In laying the bricks, particular care must be taken to fill the joints perfectly with mortar, that no leakage may take place through the walls, which, for better security, may be painted on the outside with a mixture of coal tar and clay. This forms an extremely hard and strong cover, which is not at all liable to break. The clay is dissolved in water, and put first over the brick wall, like a wash; the tar is then painted on before it has become perfectly dry.

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* URE's Dictionary of Arts and Mines, vol. i., p. 685.
† OVERMANN's Treatise on Metallurgy, p. 364.

In order to secure strength and close joints, the walls must be at least 14 inches thick, consisting of a lining of fire-brick 5 inches in width, and red brick 9 inches. Both the lining and rough wall must be well bound together by occasional binders, which unite the red and the fire-brick. The arch may be of 5-inch fire-brick; but as the space is wide, there is no harm done in making a 10-inch roof. Many kilns are built of red brick only; to this there is no objection, they answer equally as well as if lined with fire-brick; but, in this case, the common bricks ought to be made of a kind of loam which will stand fire well. If this loam contains too much iron or lime, the bricks of the roof will soon shrink and drop. It is, therefore, necessary to test the red bricks in a strong fire before a kiln is built of them, at least those used for the lining and the roof; if they resist a high red heat without melting, they may be considered good for this purpose. When a little more expense is no consideration, it is a good plan to increase the strength of the side walls by bracing them with pillars. At each end there is an iron door, 6 feet wide and 8 feet high, so that a railroad car may be run into the oven, loaded with wood, or to take off charcoal. All the kilns in use resemble the above more or less; in some cases the roof is less steep, to gain room; in others the binders are made of cast-iron uprights, and wrought-iron cross girders. In some, the gases are drawn off by a series of vents in the top of the roof; in others, by vents at both ends; when this is the case, the vent holes are provided with iron doors. In all cases, a series of draught holes is provided quite round the foot of the kiln, and by stopping one, and opening another, the access of air, and consequently the fire, is regulated. These apertures are of the size of a brick 10 inches by 2½ in height, so that a brick may fill one.

The operation of charring in these kilns is extremely simple. The wood is laid flat on the floor and piled up to the roof. It may also be set upright, but as this is more laborious it is not generally done; still there is no doubt that the coal is stronger from the billets which are standing than from those which are laid flat. The fire is applied in various ways; some prefer putting it at the top, in the middle of the arch, and drawing it gently downwards; others form a channel of brands, dry chips, or charcoal, through the middle of the floor, and apply fire at both ends; others, again, ignite the wood at the draught holes round the foot of the oven. Of all these plans, the latter is the most objectionable, for it necessarily causes a waste of wood, and makes weak coal. With a channel through the middle, firing at both ends is better, but the best plan is firing on the top, particularly in wide ovens. In all cases the wood that is charred ought to be well seasoned, for wet or green wood yields 20 per cent less coal than dry; or, in case seasoned wood cannot be had, the charring ought to be conducted with extreme slowness; the fire should be applied at the top, and fed by coal or brands. A liberal supply of fresh air should be allowed to pass through the interior. Charring green or wet wood is, in no case, profitable, and in order to obtain the best yield and greatest amount of coal, the wood, as it is delivered at the yard, should be stored under cover and protected against the rain. One heat may be performed in a week, so that an oven may be reckoned to produce from 1200 to 1500 bushels of coal in that time; but generally two or three weeks are occupied in charging, charring, and dis-discharging a kiln. It is not difficult to conduct the charring in these ovens, when the walls are perfectly air-tight, but if they are not so it is rather troublesome, and causes considerable loss of wood. When the watery vapours at the top of the kiln or at the vents cease, and no smoke of any kind issues, but a whitish blue gas makes its appearance,—which is often the case at the third day after fire is applied, although more generally on the fourth or fifth day—the vents are stopped up, and as the fire becomes visible at the apertures near the base, these are also successively stopped. When satisfied that the heat has spread throughout the interior, all the openings are well stopped by bricks, and secured by a layer of fine sand, to prevent the access of air. Two, or at the most four, days of cooling, are sufficient to deaden the coal so far as to make it ready for drawing.

These kilns are the best for the manufacturer of metals.

The ovens frequently used in Sweden are from 25 to 30 feet wide, 17 or 18 feet high, and of equal length; they are provided with a pointed arch, 2 feet thick, and the side walls are still thicker. These furnaces are likewise constructed for collecting the products of combustion, for which purpose they answer well; but, on the other hand, a light coal is produced by their use.

Chabeaussière's kiln,* for making wood charcoal, is represented in Figs. 67 and 68. Fig. 67 is a vertical section, and Fig. 68 a half bird's-eye view, and half cross section of the height of the pit bottom. *a* is the oven; *b*, vertical air pipes; *c*, *c*, horizontal flues for admitting air to the kiln; *d*, *d*, small pits which communicate by short horizontal ones, *e*, *e*, with the vertical ones; *f*, the sole of the kiln, a circle of brick-work, upon which the cover, or hood, *h*, reposes;

FIG 67.

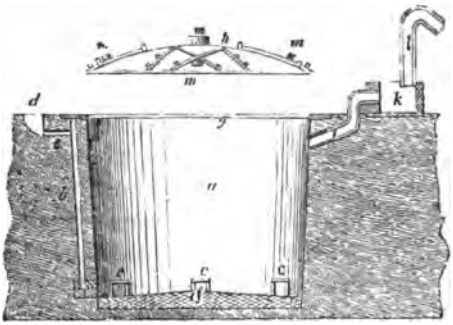
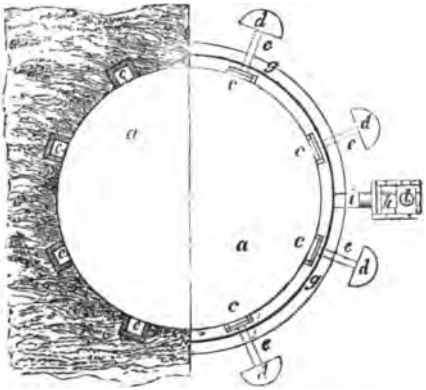


FIG. 68.



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* URE's Dictionary of Arts and Mines, vol. i., p. 685.

*i*, a pipe which leads to the cistern, *k*; *l*, the pipe destined for carrying off the gaseous matter; *m*, *m*, holes in the iron cover or lid.

The distribution of the wood is like that in the horizontal *meiler*, or heaps; it is kindled in the central vertical canal with burning fuel, and the lid is covered with a few inches of earth. At the beginning of the operation, all the draught flues are left open, but they are successively closed, as occasion requires. In eight kilns of this kind, 500 decasters of oak wood are carbonised, from which 15,000 hectolitres of charcoal are obtained, equal to 64,000 lbs. French, being about 25 per cent, besides tar; 3000 velts of wood vinegar, of from 2° to 3° Baumé, are also produced.

Charcoal obtained by the action of a rapid fire in close vessels, is not so solid and good a fuel as that which is made in the old way, by the slow calcination of pyramidal piles covered with earth. One of the most economical ovens for making wood charcoal is that invented by M. Foucauld,* which he calls a *shroud* or *abri*. To construct one of these, 30 feet in diameter at the base, 10 feet at its summit, and from 8 to 9 feet high, he forms, with wood 2 inches square,

FIG. 69.

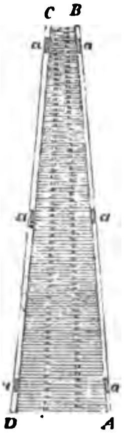

FIG. 70.

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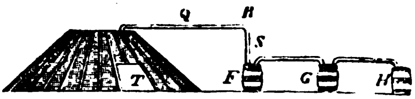
[*] URE'S Dictionary of Arts and Mines, vol. i., p. 686.

a frame 12 feet long, 3 feet broad at one end, and 1 foot at the other. The figures 69—72 will explain the construction. The uprights, A, B, and C, D, of this frame, are furnished with three wooden handles, *a*, *a*, *a*, and *a'*, *a'*, *a'*, by means of which they can be joined together, by passing through two contiguous handles a wooden fork, the frame being previously provided with props, as shown in Fig. 67, and covered with loam mixed with grass. A flat cover of 10 feet diameter, made of planks well joined, and secured by four cross bars, is provided with two trap doors, M, N (Fig. 72) for giving egress to the smoke at the commencement of the operation; a triangular hole, P, cut out in the cover, receives the end of the conduit, Q, R, S (Figs. 71 and 72) of wood formed of three deals destined to convey the gases and condensed liquids into the casks, F, G, H. Lastly, a door, T, which may be opened and shut at pleasure, permits the operator to inspect the state of the fire. The charcoal produced by this *abri* has been found of superior quality.

FIG. 71



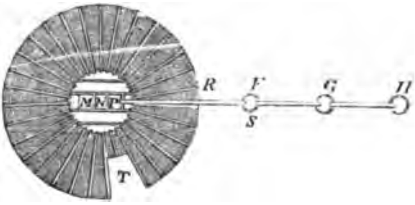


FIG. 72.

When it is thought desirable to change the place where the *abri* is erected, and to transport it to a store of new-felled timber, the frame is taken down, after beating off the clay which covers it; the joints and also the ends of the forks which fixed the frames to one another, are then cut with a saw. This process is economical in use, and simple and cheap in construction, since all the pieces of the apparatus are easily moved about, and may be readily mounted in the forest.

The carbonisation of wood is sometimes effected by means of hot air, or by the application of waste gases of blast furnaces,[*] of steam,[†] and sometimes also of blast.[‡]

Generally speaking, carbonisation with the admission of air yields less charcoal, and does not admit of an easy collection of the volatile products of carbonisation[||] (tar and pyroligneous acid). It is usually employed in the production of charcoal for metallurgical processes. Closed ovens admit of a greater yield of coal and of an easy collection of the volatile products; but, on the other hand, they necessitate the consumption of a considerable quantity of fuel for the production of the temperature required for carbonisation. They are usually capable of containing only small quantities of wood, and the resulting coal is easily combustible, owing to the large amount of volatile substances it contains.

The chemical reactions which take place in the process of carbonising wood have lately been elaborately described by Ebelmen[§] and Violette.[¶]

The yield[**] of charcoal in *meilern* is stated by Karsten to vary, according to the temperature and the quickness of the process of carbonisation, between 25 and 27 per cent by weight, and to amount to 80 per cent at the highest by volume, but to only 65 per cent if calculated from the volume of the solid wood. In carbonisation wood shrinks in length from 10 to 12 per cent.[††]

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[*] DINGL., lxiv., 392. Ann. d. Min., 3 sér., ix., 173. B. u. h. Ztg., 1842, pp. 266, 288.

[†] Bgwkfd., vii., 410. B. u. h. Ztg., 1844, p. 43. DINGL., lxxxviii., 347. Polyt. Centr., 1849, p. 538.

[‡] B. u. h. Ztg., 1843, p. 20.

[||] WEEKE, Tabelle über die Producte d. Destillation des Holzes, DINGL., xxxi., 473. Holzessiggewinnung aus Meilern zu Freiberg und am Harz. LAMP., Fortschr., 1839, p. 30. Polyt. Centr., 1851, p. 1282; 1853, pp. 317, 1016, 1515.

[§] Bgwkfd., vii., 209; x., 161. B. u. h. Ztg., iii., 505.

[¶] DINGL., cxxiii., 117. Polyt. Centr., 1852, p. 355; 1854, p. 361.

[**] DINGL., xxxv., 396. Bgwkfd., iii., 1433. ERDM., J. f. ök. u. techn. Chem., viii., 137. LAMP., Fortschr., 1839, p. 27. Jahrb. f. d. sächs. Berg. u. Hüttenm., 1829, p. 146.

[††] Bgwkfd., iii., 433.

According to Tunner,* the shrinkage of wood in length amounts to 8 or 10 per cent, and to the same in section, the total shrinkage, therefore, is from 15 to 25 per cent. The yield of charcoal at Turrach, in a well-conducted process of carbonisation in *meilern*, amounted to from 60 to 65 per cent when measured in solid mass from the compact body of wood employed; to this must be added 25 per cent of loss by shrinkage, and the yield, therefore, amounts to from 85 to 90 per cent by volume. From 10 to 15 per cent of wood are burnt to produce the temperature required for carbonisation. In calculating by weight, from 23 to 27 per cent of air-dry coal resulted from rather moist billets, whilst Karsten asserts that, under the most favourable circumstances, from 25 to 27 per cent only result when air-dry wood is charred in retorts, without taking into consideration the wood that is used for heating the retorts.

Again, other investigators† have stated that, in a well-conducted process carried on in *meilern*, from 60 to 75 per cent of coal by volume result, and about 80 per cent when the process of carbonisation is carried on in closed vessels.

Standing *meiler* in the Hartz, containing from 4000 to 6000 cubic feet of wood, yield, on an average, the following quantities:—

| | | |
|---|---|---|
| Beech wood in billets . . | 20·0—22·0 per cent by weight. | |
| | 50·0—54·5 ,, | volume. |
| Pine ,, ,, . . | 23·0—25·0 ,, | weight. |
| | 60·0—72·5 ,, | volume. |
| Pine ,, sticks . . | 21·0—25·0 ,, | weight. |
| | 50·0—65·3 ,, | volume. |
| Pine ,, stumps . . | 20·0—23·6 ,, | weight. |
| | 41·7—50·0 ,, | volume. |
| Pine ,, thin branches | 19·0—22·0 ,, | weight. |
| | 38·0—48·0 ,, | volume. |

The production of 100 cubic feet of coal requires 180 cubic feet of fir-wood in billets, 200 cubic feet of beech-wood in billets, 240 cubic feet of pine-wood in stumps, or 320 cubic feet of oak or beech wood in sticks.

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* TUNNER, Stabeisen- u. Stahlbereitung, i., 27.

† Bgwkfd., iii., 1.

The following table[*] of the quantity of charcoal yielded by different woods, was published by Mr. Mushet as the result of experiments carefully made upon a small scale. He says, the various woods before being charred were thoroughly dried, and pieces of each kind were selected as nearly alike in every respect as possible. One hundred parts of each sort were taken, and they produced charcoal as follows:—

| | | | |
|---|---|---|---|
| Lignum vitæ | yielded | 26·0 | of a greyish colour, resembling coke. |
| Mahogany | ,, | 25·4 | tinged with brown, spongy and porous. |
| Laburnum | ,, | 24·5 | velvet black, compact, very hard. |
| Chestnut | ,, | 23·2 | glossy black, compact, firm. |
| Oak | ,, | 22·6 | black, close, very firm. |
| Walnut | ,, | 20·6 | dull black, close, firm. |
| Holly | ,, | 19·9 | dull black, loose, and bulky. |
| Beech | ,, | 19·9 | dull black, spongy, firm. |
| Sycamore | ,, | 19·7 | fine black, bulky, moderately firm. |
| Elm | ,, | 19·5 | fine black, moderately firm. |
| Norwegian pine | ,, | 19·2 | shining black, bulky, very soft. |
| Sallow | ,, | 18·4 | velvet black, bulky, loose and soft. |
| Ash | ,, | 17·9 | shining black, spongy, firm. |
| Birch | ,, | 17·4 | velvet black, bulky, firm. |
| Scotch pine | ,, | 16·4 | tinged with brown, moderately firm. |

Messrs. Allen and Pepys, from 100 parts of the following woods, obtained the following quantities of charcoal:—

| | |
|---|---|
| Beech | 15·00 |
| Mahogany | 15·75 |
| Lignum vitæ | 17·25 |
| Oak | 17·40 |
| Fir | 18·17 |
| Box | 20·25 |

It is observable that the quantities obtained by Messrs. Allen and Pepys are, in general, less than those given by Mr. Mushet, which may be owing to Mr. Mushet not having applied sufficient heat, or operated long enough to dissipate all the aqueous matter or gaseous products.

The following facts concerning the yield of charcoal are stated by Overmann[†]:—

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[*] URE's Dictionary of Arts and Mines, vol. i., p. 687.

[†] OVERMANN's Treatise on Metallurgy, p. 360.

In heaps or pits the best coal is generally found about one foot above the floor, and at an equal distance from the roof; in the centre the coal is weak. This shows that large pits are more favourable for the production of good charcoal than small ones, and that the fire in the centre should work as slowly as possible, for it is the rapid charring which injures the coal in the middle of the pit. Most of the brands are generally found near the floor, and where the work has been good they amount to 1-12th of the charcoal in large pits, and to 1-6th in small ones; a larger amount of brands shows bad work.

The quantity of charcoal thus obtained from a cord of wood varies from 25 to 45 bushels. If the wood is cut and corded during the winter and charred in summer, a skilful burner will obtain, on an average, 40 bushels of good charcoal from a cord. There are many circumstances which tend to modify the amount of this yield. If the wood is badly chopped, or ill-trimmed and short, or the measure too small, it will not yield well; green wood yields badly, and causes weak coal. Coal charred in winter or stormy weather is always poor, and the quantity small. Green dust, or that which cakes, also causes weak coal and a bad yield; light and porous dust will often produce good coal, though in small quantities. The best dust is that which has been used for a few brands, and is well mixed with small coal. A heat that is too strong at the commencement causes weak and small coal, and if continued throughout the operation always results in little coal, and that of bad quality. Young wood makes a stronger coal and gives a better yield than old wood, provided proper care is taken in charring. Careless workmen invariably make but little coal, and if they are inexperienced also, weak coal is sure to be produced.

It may be more convenient to purchase coal by measure than by weight, but certainly this is not the most correct method, neither is it the best for either seller or buyer. Hard strong coal is, in all smelting operations, of greater value than soft coal, and in consequence of buying coal by measure, we tempt burners to make soft coal and much of it. On the other hand, as there is but little difference in weight in strong and weak coal, it is certainly more advantageous to the smelter that it should be strong. In all cases of charring, no matter in what form, or by what means, a well-conducted operation will furnish from 20 to 23 lbs. of charcoal from 100 lbs. of seasoned wood. The coal may be weak or strong, but neither more nor less than the above-mentioned quantity ought to be produced. Slow charring and low heat will produce the largest amount of coal, but it will be weak; a brisk heat, well conducted, will furnish less, but will make a strong coal. This determines which mode of charring is the most profitable to the smelter. With a well-conducted operation in a pit containing at least 50 cords of wood the yield for air-dried wood ought to be in the proportion shown in the following table:—

| Kind of Wood. | Yield by Weight. | Yield by Measure. |
|---|---|---|
| Oak . . . | 23 per cent. | . 74 per cent. |
| Beech . . | 22 ,, | 73 ,, |
| Pine . . . | 25 ,, | 63 ,, |

A cord of 128 cubic feet of oak ought to furnish 64 bushels of 2600 cubic inches each; pine wood must yield 54 bushels of the same size. This measure is actually reached by good burners, though not by the average of workmen. The best means of obtaining a large yield and good coal is by using large pits; there is little difficulty in making 50 bushels of coal in a pit containing 200 cords of pine wood, or, if it contains hard wood, 60 bushels, and the coal may be as strong as the yield is good.

Overmann* has calculated the cost of making charcoal in America in pits as well as in ovens, both of which methods are carried on there to a great extent—

" On examining the quantity and quality of charcoal obtained by either method of charring, we find that local circumstances determine which is best to adopt. In the pit or heap we can obtain, with perfect regularity, 20 per cent of coal from seasoned wood. The oven will not make more than 25 per cent, which yield may be reached by having a heavy cover, and with slow charring in the pit. So far kilns and pits are nearly on an equality as to the amount of the yield, at least there is not more than 10 per cent in favour of the kiln. The wages paid for charring in pits where the wood is delivered is from 1½ to 2 cents per bushel, and in ovens it is about ¾ to 1 cent for the same quantity. If a cord of wood makes, on an average, 40 bushels in the pit and 45 in the kiln, the amount in the kiln cannot be regarded as more than that of the pit, although the measure may be more, because the coal in the former is lighter than in the latter. The transport of the coal from the woods to the furnace yard causes a loss of 10 per cent, which is also in favour of the kiln. All the advantages of the kiln over the pit amount to 20 per cent, from which the interest of the investment in ovens is to be deducted. All the other circumstances are equal, for the wood must be stored under sheds as well as the coal, and there is no advantage in favour of either. If 40 bushels is the capacity of the pit, and 50 bushels of the kiln, we gain from the cord of wood, by using the latter, 10 bushels of charcoal. If the price of a cord of wood is 40 cents, which may be considered the lowest, and which prevails only in the Western and Southern States, one bushel of charcoal made in the pit will cost 2¾ cents, or say 3 cents, in the wood, and in the furnace yard, exclusive of hauling, 3⅔ cents, including loss; or the coal from a cord of wood will cost 1 dollar and 41 cents. Coal made from the same kind of wood in the kiln will cost 90 cents per cord of wood, that is, the wood costs 40 cents for chopping and lease, and the charring 50 cents. Here are 51 cents per cord of wood gained over the pit in the furnace yard, or nearly 33 per cent in favour of the oven. When the wood is in the yard, the coal of the pit will cost but 3⅓ cents per bushel, or 1·30 dollars per cord of wood, which somewhat reduces the advantages of the oven. But from this it is evident that when the wood is at the furnace, the oven is decidedly preferable to the pit. If the wood or charcoal has to be hauled from a distance, it will depend on that distance and the means of transport, whether it is more profitable to char in ovens or in pits. At the lowest price of wood the oven is 50 cents more profitable per cord than the pit, and as the coal of 5 cords of wood, say 4 cords, is equal to 1 cord of wood in weight, these 50 cents taken four times and divided by three, or 66 cents, is the price which may be paid for hauling one cord instead of the coal made of it. If the cartage of wood costs more than this, there is no advantage in bringing it to the yard. When the cost of a cord of wood exceeds 40 cents it is still more advantageous to use the oven. If a cord of wood costs 2 dollars, and the advantages, exclusive of labour, are 20 per cent, which makes 40 cents on a cord, the difference in wages for charring being 30 cents on a cord, the price paid for hauling wood instead of coal to the yard may be—

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* OVERMANN'S Treatise on Metallurgy, p. 370.

$$\frac{40+30\times4}{3} = 93 \text{ cents on the cord,}$$

before the methods become equally beneficial. If these favourable circumstances can be secured in carting wood the oven has its advantages, but not otherwise."

The above-stated yield of charcoal from different woods differs with various investigators, for the reason that it is very difficult to ascertain the exact cubical measurement, and also because the yield is influenced by the age of the wood, its state of moisture, and the temperature which has been employed at the process of carbonisation. When rapid charring at a quickly raised temperature takes place, only 12 or 16 per cent of coal is produced, while the yield will amount to 24 or 28 per cent when the temperature is slowly raised, because, at a rapidly increased temperature, the watery vapour will combine with a part of the carbon, forming carbonic oxide gas and hydrogen; on the other hand, when the process is carried on at a slowly increased temperature, the greater part of the water will be evaporated before carbonisation commences. The greatest yield of coal will, therefore, result when the process is commenced at a low temperature, which, towards the end, is gradually increased.

Violette produced from 30 to 45 per cent of coal from various kinds of wood, all of which he carbonised at an equal temperature; this proves that the nature of the wood also exerts an influence on the yield of coal.

Good charcoal looks bluish-black, glistening, and has a glossy conchoidal fracture. Being of decreased volume, it has the shape and structure of the wood from which it was produced.* When struck it rings, and that which is well charred is hard and does not soil the fingers on being fractured afresh. It burns steadily, without emitting smoke, and, when in small pieces, without flame also. Large pieces burn at the commencement with a little shining flame, owing to the volatile combustible substances which the coal contains in its pores. Compact, fresh coal, especially that produced from larch wood, has the hurtful property of decrepitating, and producing a great deal of small coal. The coal yielded by very porous, young, or rotten wood, is too loose and of slight heating power. Brands, that is to say, charcoal which is not perfectly carbonised, have also a conchoidal fracture, some glisten and do not soil the fingers, but, when broken lengthwise, they appear of a reddish colour, do not ring, have a greater specific gravity than good charcoal, and, on burning, give the more flame if in a very raw state. For some purposes, these brands are intentionally produced† An admixture of sand, earth, and stones, contained in charcoal, has an injurious influence on the finery process. When coal of this kind is employed for the Lancashire method (vol. ii., page 763) it is sometimes stirred with water in a deep basin immediately before being used.

Charcoal contains more or less cracks in all directions, but they most frequently run from the centre as radii. Soft coal has more cracks than hard coal.

Even the most compact coal is friable; care must, therefore, be taken not to store it in too high heaps; without this precaution the loss caused will amount to about 5 per cent by volume.

Charcoal is more difficult to ignite than wood, especially if the coal is compact. According to Berthier, ignition takes place at 240° C.; Reich states that coal of pine wood ignites at 280° C., and Violette considers 370° C. to be the temperature at which charcoal ignites.

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* HAUSMANN, Molekularbewegungen, 1856, p. 86.

† DINGL., lxviii., 209; lxix., 396; cix., 137; cx., 189. Bgwkfd., i., 468. ERDM., J. f. pr. Chem., vi., 223. Ann d. Min., 3 sér. xiii., 487; xvi., 657. HAUSMANN, Stud., iv., 388.

Ignited coal glows for a longer or shorter period; if the coal was charred at high temperature, it will glow for a short time only. The conducting power of heat in coal increases with the temperature at which the coal is produced.

Fresh charcoal absorbs water and air from the atmosphere, causing it usually to increase in weight from 8 to 15 per cent, according to the compactness of the coal, and both a very loose and very compact coal increase less in weight than one of a medium compactness. Messrs. Allen and Pepys* found that by a week's exposure to the air, the charcoal of

| | | |
|---|---|---|
| Lignum vitæ gained | 9·6 | per cent |
| Fir ,, | 13·0 | ,, |
| Box ,, | 14·0 | ,, |
| Beech ,, | 16·3 | ,, |
| Oak ,, | 16·5 | ,, |
| Mahogany ,, | 18·0 | ,, |

The following is a tabular view of the volumes of different gases which were absorbed in the course of twenty-four hours, by one volume of charcoal, in the experiments of M. Theodore de Saussure, which were conducted in a manner likely to produce correct results. Each portion of charcoal was heated afresh to a red heat, and allowed to cool under mercury. When taken from the mercury, it was instantly plunged into the vessel of gas:—

| | |
|---|---|
| Ammoniacal gas | 90 |
| Muriatic acid gas | 85 |
| Sulphurous acid | 65 |
| Sulphuretted hydrogen | 55 |
| Nitrous oxide | 40 |
| Carbonic acid | 35 |
| Bicarburetted hydrogen | 35 |
| Carbonic oxide | 9·42 |
| Oxygen | 9·25 |
| Nitrogen | 7·50 |
| Carburetted hydrogen | 5·00 |
| Hydrogen | 1·75 |

Fresh charcoal decrepitates strongly in fire, it burns quickly, and protracts the fining of pig-iron, inducing a dry

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[*] URE's Dictionary of Arts and Mines, vol. i., p. 688.

and burning welding heat. If the application of such coal is necessary, it must be previously moistened with water. Charcoal which has been stored for a long time under a dry shelter* is more effective in the finery process than fresh coal, because charcoal absorbs from the atmosphere more oxygen and less nitrogen.

Violette states that charcoal absorbs gases and moisture from the atmosphere in less degree if produced at a higher temperature.

| Charcoal, for instance, produced at | Absorbs |
|---|---|
| 150° C. | 21 per cent |
| 250° ,, | 7 ,, |
| 350° ,, | 6 ,, |
| 450° ,, | 4 ,, |
| 1500° ,, | 2 ,, |

Charcoal, in the form of powder, absorbs twice as much water as when in pieces.

Charcoal kept on moist ground, or in contact with water, is liable to absorb two or three times its own weight of water; when this is the case, it burns slowly, and produces little heat, and it is only with great difficulty that the absorbed water can again be removed.

If charcoal is stored in the open air, it is put into pyramidal heaps on raised ground, and the surface of the heaps is covered with large pieces to prevent the rain from penetrating.

Neumann, who made many experiments on charcoal, informs us that, for the reduction of the metallic oxides, the charcoal of the heavier woods, such as oak and beech, is preferable, and that, for common fuel, it gives the greatest heat, and requires the most plentiful supply of air to keep it burning, while that of the lighter woods preserves a glowing heat with far less draught; and that, for purposes where it is desirable to have a steady and still fire, charcoal which has been made from wood, previously divested of its bark, should be employed, since it is the cortical part which crackles and flies off in sparks during combustion, while the coal of wood itself seldom does so.

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* Werlisch in Bgwkfd., iii., 513. Scheerer's Metallurgie, i., 522. Tunner, Stabeisen- und Stahlbereitung, i., 28.

**The Specific Gravity of Charcoal.**—Accepting the specific gravity of water to be = 1000, that of all the various woods in powdered state, will be larger, and amount to about 1520. The specific gravity of charcoal varies with the temperature applied in the process of carbonisation:—

| Temperature. | Specific Gravity. |
|---|---|
| 150—270° C. | 1400—1500 |
| 1500° C. | 2000 |

According to Rumford, the specific gravity of charcoal depends on that of the wood from which the coal was produced; wood of low specific gravity, therefore, yields coal of low specific gravity. Hassenfratz and Werther's* experiments have, however, shown that coal from soft wood may sometimes have greater specific gravity than that from hard wood.

Storch† considers the specific gravity of charcoal to be the indication of its quality.

Compact charcoal contains more carbon than an equal volume of less compact coal, and has, therefore, a greater heating power than the latter if combustion is carried on with a sufficient pressure of blast. In cases where no very high temperature is required, in finery fires, for instance, less compact coal, burnt at a low pressure of blast, may economically be of greater advantage than the more compact kinds of charcoal.

**Composition of Charcoal.**—According to Violette,‡ charcoal produced at the same temperature from various kinds of wood does not possess the same elementary composition, as, for instance, the amount of carbon in 72 kinds of coal varied by 15 per cent. The composition of coal does not, therefore, depend only on the temperature of the process of carbonisation, but also on the nature of the wood. Even charcoal produced at a temperature equal to the fusion point of platinum does not consist of pure carbon, but has the following composition:—

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* Erdm., Journ. f. pr. Chem., lxi., 21. Polyt. Centr., 1854, p. 248.

† Polyt. Centr,, 1847, p. 295.

‡ Dingl., cx., 189; cxxi., 102; cxxiii., 117, 132, 185, 291. B. u. h. Ztg., 1852, p. 254. Erdm., Journ. f. pr. Chem., Bd. 67, p. 385.

| | |
|---|---|
| Carbon | 96·517 |
| Hydrogen | 0·623 |
| Oxygen | 0·936 |
| Ash and loss | 1·946 |

The composition of pine-wood charcoal, produced at a temperature equal to the fusing point of antimony, is as follows, the coal being analysed immediately after the process of carbonisation was ended :—

| | |
|---|---|
| Carbon | 81·970 |
| Hydrogen | 0·961 |
| Oxygen | 15·250 |
| Ash | 1·160 |

Whilst, supposing that the charcoal, on exposure to the atmosphere, absorbs 16 per cent of moisture and air, its composition will be thus—

| | |
|---|---|
| Carbon | 70·45 |
| Hydrogen | 1·68 |
| Oxygen | 13·10 |
| Ash | 1·00 |
| Air and moisture | 13·76 |

Common charcoal contains, on an average, 3 per cent of ash ; and when kept in store, from 10 to 20 per cent, or, on an average, 12 per cent of hygroscopic water.

The following table shows the heating power and the specific gravity* of various kinds of charcoal :—

| | Heating Power. C = 1. | | | 1 part in weight of Charcoal reduces Lead. | Specific Gravity. |
|---|---|---|---|---|---|
| | Absolute. | Specific. | Pyrometric. | | |
| Black charcoal, perfectly dry, containing 3 per cent of ash | 0·97 | — | 2450 | — | — |
| Black charcoal, air-dried, containing 3 per cent of ash and 12 per cent of hygroscopic water .. .. .. | 0·84 | — | 2365 | — | — |
| Birch charcoal, perfectly dry, containing 3 per cent of ash | — | 0·20 | — | 33·71 | 0·203 |
| Ash charcoal, perfectly dry, containing 3 per cent of ash | — | 0·19 | — | — | 0·200 |
| Red beech charcoal, perfectly dry, containing 3 per cent of ash .. .. .. .. .. | — | 0·18 | — | 33·57 | 0·187 |
| Red pine charcoal, perfectly dry, containing 3 per cent of ash .. .. .. .. .. | — | 0·17 | — | 33·51 | 0·176 |

* Bgwkfd., xi., 214. Polyt. Centr., 1847, p. 295. DINGL., xiv., 135 ; xviii., 377.

| | Heating Power. C − 1. | | | 1 part in weight of Charcoal reduces Lead. | Specific Gravity. |
|---|---|---|---|---|---|
| | Absolute. | Specific. | Pyrometric. | | |
| Maple charcoal, perfectly dry, containing 3 per cent of ash | — | 0·16 | — | — | 0·164 |
| Oak charcoal, perfectly dry, containing 3 per cent of ash | — | 0·15 | — | 33·74 | 0·155 |
| Alder charcoal, perfectly dry, containing 3 per cent of ash | — | 0·13 | — | 32·40 | 0·134 |
| Lime charcoal, perfectly dry, containing 3 per cent of ash | — | 0·10 | — | 32·79 | 0·106 |
| Fir charcoal, perfectly dry, containing 3 per cent of ash | — | — | — | 33·53 | — |
| Willow charcoal, perfectly dry, containing 3 per cent of ash .. .. .. .. .. .. | — | — | — | 33·49 | — |
| Perfectly dry red charcoal .. | — | — | 2260 | — | — |
| Red charcoal, containing 10 per cent of moisture.. .. | — | — | 2190 | — | — |

One part by weight of the different kinds of charcoal heated, on an average, 75·7 parts of water from 0° to 100° C.

According to this table, the specific heating power of charcoal free from water stands in direct proportion to the respective specific gravity, and is lower than that of the corresponding kinds of wood; this difference will be the larger if the wood, on carbonisation, shrinks to a great extent.[*]

**Practical Results.**—With regard to the effect of charcoal, the following experiments have been made in practice:—

1. Equal volumes of hard charcoal produce a greater temperature than soft coal, and one part by volume of hard coal is usually considered equal in effect to 1½ parts of soft coal. There is little difference in the heating power if equal weights of the two kinds of charcoal are employed, although soft charcoal usually has somewhat more effect, as it is more porous, and, consequently, more easily combustible.

2. The heating power of charcoal is more than twice as large as that of an equal weight of wood. This difference is not quite so large, though still considerable, if we compare charcoal and wood by volume.

3. According to Karsten, the effect of charcoal compared with coke, in iron blast furnaces which are carried on with hot blast, stands in the following proportion:—

100 parts in volume of charcoal = 40 parts in volume of coke.
100 ,, weight ,, = 125 ,, weight ,,

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[*] Erdm., J. f. pr. Chem., xvii., 65; lviii., 319. Polyt. Centr., 1853, p. 694.

The following is the proportion when pig-iron is re-melted in cupola furnaces :—

100 parts in volume of charcoal = 22¼ parts in volume of coke.
100 ,, weight ,, = 83⅓ ,, weight ,,

4. Including the interstices, the following is the absolute weight of various kinds of charcoal* :—

| Cubic Feet. | | Charcoal. | | lbs. | |
|---|---|---|---|---|---|
| 1 | (Hessian) | Beech made of billets | weighs from | 8—9 | (Hessian) |
| 1 | ,, | ,, ,, thick sticks | ,, | 7—7¼ | ,, |
| 1 | ,, | Oak ,, billets | ,, | 7—8 | ,, |
| 1 | ,, | ,, ,, sticks | ,, | 6—6½ | ,, |
| 1 | ,, | Soft | ,, | 4½—5½ | ,, |
| 1 | ,, | Pine | ,, | 5½—7 | ,, |
| 1 | (Hanoverian) | Hard | ,, | 10—10½ | (Hanov.) |
| 1 | ,, | Soft | ,, | 6—6½ | ,, |
| 7·11 | Prussian | Scotch Fir | ,, | 64 | (Prussian) |
| 1 | ,, | ,, | ,, | 11—11·6 | ,, |
| 1 | ,, | Oak and Beech mixed | ,, | 14—15 | ,, |
| 1 | ,, | Pine | ,, | 7—8½ | ,, |
| 1 | ,, | Fir | ,, | 7—9 | ,, |
| 1 | ,, | Larch | ,, | 8—9½ | ,, |
| 1 | ,, | Birch | ,, | 8—10 | ,, |
| 1 | ,, | Fir | ,, | 8½—10 | ,, |
| 1 | ,, | Beech | ,, | 11—13 | ,, |
| 1 | ,, | Oak | ,, | 12—15 | ,, |

5. According to Karmarsch,† one pound (Hanoverian) of beech charcoal evaporates 118 loth (Hanoverian) of water, in experiments on a small scale. Experience shows that the total quantity of heat produced by burning one pound of charcoal, gives as much as is required to evaporate 13 lbs. of water of 23° C., therefore little more than a quarter of the heat produced is utilised. The loss of heat in well constructed and skilfully managed fire-places for heating boilers amounts, on an average, to 1-6th or 1-5th; one pound of charcoal, therefore, really evaporates 10½ lbs., or 336 loth.

6. According to experiments made by the Society for Promoting Industry in the Kingdom of Prussia,‡ one pound of fir charcoal containing 10·5 per cent of water, and 2·7 per cent of ash, converts 6·78 lbs. of water of 0° C. into steam of 110° to 115° C., and this coal, when perfectly dried, and containing 3·02 per cent of ash, converts 7·59 lbs. of water of 0° C. into steam of 110° to 115° C.

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* Bgwkfd., ix., 154.

† Mittheilungen des Gew.-Ver. f. d. Königr. Hanover, 1835, p. 313.

‡ Ibid., p. 207.

## TURF.

Turf[*] or peat consists of vegetable matter, chiefly of the moss family, in a state of partial decomposition, caused by the action of water; this substance is, at the present time, being formed in stagnant water in which plants have sunk to the bottom after they have dried, in consequence of the change of the seasons (page 298). The further this process of decomposition has advanced, the richer the turf will be in carbon, the darker its colour, and the more it will lose the original texture of the plants. The dense black turf which forms the lower stratum of a turf moss is much contaminated with iron, sulphur, sand, &c., and is sometimes found in a pasty state (Baggertorf), owing to its standing under water; the lighter turf of the upper strata, though nearly pure vegetable matter, is too bulky for transportation, and too porous for manufacturing purposes. The heating power of the kinds of dense turf is very considerable, even exceeding that of many varieties of brown coal, that is, calculating by weight, and supposing the turf to be air-dried.

Karmarsch[†] has classified turf according to age, thus:—

1. **Young Turf**, of white, yellow, brown, or black colour, with a distinct organic structure;

2. **Old Turf**, of darkish brown or black colour, almost without any organic texture, and rarely containing undecomposed woody substances; some varieties of the old turf show an earthy fracture, they are then termed earthy turf or "*Erdtorf*;" others have a conchoidal fracture, and are called pitch turf or "*Pechtorf*."

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[*] MOSER, Torfbetrieb u. Torfbenutzung aus eigenen Erfahrungen dargestellt, 1840. PAPIUS, die Lehre vom Torfe., 1845. DÖHLA, Kurze practishe Anleitung über Torf, &c., 1837. WIECK, Torfbüchlein, 1839. LEO, das gesammte Torfwesen, 1860. Ueber Gewinnung und Benutzung des Torfs in Baiern: München, bei Wolf, 1839. VOGEL, der Torf, seine Natur und Bedeutung: München, 1859. WALLAND, über Torf, dessen Gewinnung, Trocknung, und Verkohlung. Polyt. Centr., 1855, p. 1112, Nos. 18, 21. Sächs. Bergwerksztg, 1854, No. 1. TUNNER'S LEOB., Jahrb., 1860, p. 334. B. u. h. Ztg., 1854, p. 43; 1857, p. 195; 1858, pp. 269, 249, 379.

[†] Mittheilungen des Gew.-Ver. f. d. Königr., Hanover, 1835, p. 311; 1840, p. 56; 1853, pp. 211, 273.

The following table shows the quality of these varieties of turf:—

| | 1 cubic foot (Hanoverian) weighs lbs. (Hanov.) | Specific Gravity. | 1 lb. evaporates Water. loth.[*] | 1 cubic foot evaporates Water. lbs. | Amount of Ash. per cent. |
|---|---|---|---|---|---|
| White and yellow turf | 6—14 | 0·113—0·263 | 49—61 | 11·28—23·37 | 0·5—14 |
| Brown and black turf | 13—36 | 0·240—0·676 | 52—73 | 23—67 | 0·5—14 |
| Earthy turf . . . . | 22—48 | 0·410—0·900 | 53—72 | 57—58 | 1·25—39 |
| Pitch turf. . . . . | 33—55 | 0·620—1·030 | 58—73 | 57—59 | 1—8 |

The figures of the third column are ascertained by means of a small boiler apparatus, and when they are multiplied by 2¼, and the product divided by 1·1932, that quantity of water of 0° C. will result, which may be converted into steam of 103° C. on a large scale by burning 1 lb. of turf; thus, light turf will convert from 2·89 to 3·59 lbs. of water, light turf formed of the roots of plants (Wurzeltorf) from 3·09 to 4·33 lbs., earthy turf from 3·13 to 4·29 lbs. of water, and pitch turf from 3·42 to 4·33 lbs., or, on an average, 3·35, 3·80, 3·69, and 3·91 lbs. of water respectively.[†]

The young turf which, owing to its contents of fibres, roots, &c., has sufficient consistency, is cut in a very simple manner. The surface matter being removed, a peculiar kind of spade, called a slade, is employed. This is a long spade, with a portion of the blade turned up at right angles on one side. With this the turf is cut out in the shape of thick bricks. The earthy kinds of turf not having sufficient consistency, are pressed into moulds; in Ireland[‡] they are treated as follows:—Immediately after being dug, the turf is triturated under revolving edge wheels, faced with iron plates perforated all over their surface; it is forced by the pressure through these apertures till it becomes a species of pulp, which is freed from the greater part of its moisture by squeezing in an hydraulic press between layers of caya cloth; the turf is then dried, and frequently coked in suitable ovens.

At Freudenberg and Buchscheiden, in Carinthia, the older earthy turf is divided with hatchets, a large quantity of water is thrown on it, it is then kneaded and pressed into moulds; the resulting bricks shrink a great deal in drying, and then form a dense and compact mass.

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[*] One *loth* is equal to half an ounce.

[†] Mittheilungen. d. Han. Gew.-Ver., 1853, p. 213.

[‡] URE's Dictionary of Arts and Mines, vol. iii., p. 964.

**Composition of Turf.**—The composition and properties of turf vary far more than those of wood, and this difference is founded less on the nature of the decayed roots and plants than on the various foreign admixtures, the variable state of compactness, and the degree to which the plants in the turf are modified. Freshly cut turf is very rich in water, and, on drying in the atmosphere, it may lose above 45 per cent of its weight. Air-dried turf contains, on an average, 75 per cent compact mass, including 1 or 2 per cent of ash and 25 per cent of hygroscopic water, but the amount of this water may increase up to 50 per cent.

Karmarsch considers that perfectly air-dried turf contains one-sixth of its own weight of water. The compact turf substance contains on an average—

| | |
|---|---|
| Carbon . . . . . . . | 60·63 per cent |
| Hydrogen. . . . . . . | 6·04 ,, |
| Oxygen . . . . . . . | 33·32 ,, |

or, supposing all the oxygen to have combined with hydrogen so as to form water, it contains—

| | |
|---|---|
| Carbon . . . . . . . . . | 60 per cent |
| Hydrogen . . . . . . . | 2 ,, |
| Water (chemically combined) | 38 ,, |

The air-dried turf has, therefore, the following composition, without taking into consideration the amount of ash :—

| | |
|---|---|
| Carbon . . . . . . . . . | 45·0 per cent |
| Hydrogen . . . . . . . | 1·5 ,, |
| Water (chemically combined) | 28·5 ,, |
| Water (hygroscopic) . . . | 25·0 ,, |

The ash, which turf may contain in quantities of from 1 to 30 per cent, and even more, differs from wood ash in that it contains less soluble components, and either no alkalies at all or only small quantities; on the other hand, it contains phosphoric acid,* sulphuric acid, silica combined with lime, alumina, peroxide of iron, and magnesia. According to Vogel, the amount of silica varies from a few per cents to upwards of 30 per cent; that of carbonate and sulphate of lime between 20 and 45 per cent, and is very rarely as little as 8 per cent; that of magnesia ranges between 1 and 10 per cent, and sometimes reaches 15 per cent; that of alumina is usually from 0·2 to 5 per cent, while the amount of peroxide of iron may be as large as 30 per cent, and that of phosphoric acid 2·5 per cent; alkalies are contained in turf from mere traces up to 3 per cent.

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* Dingl., ciii., 232.

Turf found in bogs on the summits of high mountains usually contains the least proportion of ash; that from the Upper Hartz, for instance, contains from 0·5 to 5 per cent. Vohl* has compared analyses of turf ash with those of the ash of the plants of which turf is formed, and this comparison has led him to the conclusion that the alkalies, as well as a great proportion of the silica, become separated in a soluble state in the process of decomposition and decay. The ash of moss turf contained—

| | |
|---|---|
| Potash . . . . . . . . | 1·027 per cent |
| Soda . . . . . . . . | 0·528 ,, |

whilst the ash of the plants from which the turf resulted contained—

| | |
|---|---|
| Potash . . . . . . . . | 8·016 per cent |
| Soda . . . . . . . . | 12·399 ,, |

The value and adaptability of turf depends chiefly on the amount of water it contains, and also on its density or compactness.

For this reason, freshly cut turf is dried in the open air (page 298), in which operation the turf that has been formed in moulds suffers more by sun and rain than that which has been cut. The best air-dried turf still contains 25 per cent of hygroscopic water, and, if otherwise of good quality, is well adapted for the production of as high a temperature as is required for puddling furnaces. If the production of still higher temperatures is intended, such, for instance, as reheating furnaces require, the turf must be dried in kilns,† at a temperature of from 100° to 120° (page 308). In this process the turf loses 40 per cent of its weight, nearly 50 per cent of its volume, and is rendered very hygroscopic. Turf in this state contains—

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* Polyt. Centr., 1859, No. 8, p. 529.

† PECLET, über die Wärme, deutch v. HARTM., 1860, Bd. 2, p. 231.

| | |
|---|---|
| Carbon . . . . . . . . . . . . . . . | 60 per cent |
| Hydrogen . . . . . . . . . . . . . . | 2 „ |
| Water (hygroscopic and chemically combined) | 38 „ |

Marsilly* states that turf undergoes a slight decomposition at a temperature of 110° C., which increases considerably at a temperature of 200° C.; a fuel of increased heating power then results, but, on the other hand, elements capable of producing heat are lost. It is therefore most advantageous to dry turf at a temperature not exceeding 100° C.

Fresh turf freezes at a temperature of from −1° to −3° C., and, on thawing, does not contract to a smaller volume, but retains its extremely porous structure; after being dried, it is very light and friable, and has but little heating power. If, however, turf has been dried to a certain degree, cold will no longer affect it.

The density of turf is very variable, but is never so great as that of wood. Turf is the more effective, and its carriage the cheaper, the more compact it is, supposing the other properties to be equal.

The following methods, in the wet and dry way, are chiefly employed to condense loose turf.†

*a.* **Condensing Turf without Pressing it.**—When turf is condensed in the wet way without pressing it, it is triturated either by treading upon it with the feet, by kneading and beating with iron rods (Holland, North Germany, South Germany) or by machines (Haspelmoor, Montauger, Rheims, Sweden, and Ireland); the turf is thus rendered more compact and, consequently, less hygroscopic; it also dries easier and more perfectly. Turf that has been cut, is sometimes triturated by means of rollers.‡ A well-conducted trituration condenses turf to one-fourth and even one-sixth of its original volume, and perhaps may, therefore, perfectly replace the more difficult and expensive method of pressing.

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* B. u. h. Ztg., 1858, pp. 287, 381.

† Ibid., 1858, pp. 168, 269. Polyt. Centr., 1858, No. 14.

‡ Berggeist, 1860, No. 20.

In order to facilitate the drying of the triturated turf, it is requisite to add as little water as possible. When a perfect elutriation, with a large addition of water, is employed, the specific gravity of the prepared turf will increase, but, on the other hand, the turf does not gain in consistency and heating power; the expenses are also considerably greater, and it is difficult to work large masses. This is the chief reason why Exter's method of preparing turf has been abandoned at Haspelmoor* in Bavaria.

The prepared turf is best dried under sheds, and, after drying, it is less inclined to absorb water again than the original turf.

This method of preparation is particularly well adapted for turf of older formation, which contains a large amount of inorganic substances. It is employed at the works of M. Challeton, at Montauger,† in France, and at St. Jean, in Switzerland. The turf is here triturated by machines containing a number of knives; stones, coarse grains of sand, remains of wood, &c., will then separate in water, and the purified mass is made to pass through a perforated metal drum, by means of brushes, thus separating the remaining roots and fibres. The fine liquefied mass of turf is now conducted through several vessels, thus affording an opportunity for the further separation of fine particles of sand and earth, and effecting a perfect mixture of the particles of turf; it then passes into a large number of basins, about 10 inches deep, and provided with bottoms formed of wooden planks, which have a number of rifts, or small clefts, thus allowing the water gradually to run off. After the lapse of a few days, the turf attains sufficient consistency; a wooden lattice work is then pressed into the mass, which, by this means, is divided into bricks, and the evaporation of water is so greatly facilitated, that a short time afterwards the bricks may be placed at the side of the basins, in order to dry. This drying must not, however, be effected too rapidly, or the bricks will crumble into pieces; reed or straw is therefore laid upon the bricks to protect them both from the sun and rain. The expenses for manipulation are thus considerably increased.

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* Vogel, der Torf. München, 1859, p; 33. B. u. h. Ztg., 1859, pp. 7, 15.

† Vogel, der Torf. München, 1859, pp. 41, 86. B. u. h. Ztg., 1858, pp. 285, 349. Ztschr. d. Ver. deutsch Ingen., ii. Bd., Hft. 1—3.

The dry turf contains, according to Challeton :—

| | | |
|---|---|---|
| Water . . . . . . . . . | 13·82 | per cent |
| Ash . . . . . . . . . . | 11·19 | ,, |
| Carbon. . . . . . . . . | 74·99 | ,, |

and its absolute heating power is less by one-fifth than that of coke. The shrinkage, or contraction of the turf, amounts to 84 or 85 per cent by volume.

Hebert's[*] method, at Rheims, is said to be preferable to that of Challeton. Turf is also condensed in the wet way at Friesack.[†]

The method of preparing turf, practised at Staltach, in Bavaria, is, according to Vogel,[‡] one of the most perfect in use. The turf is dug in the pit in large masses, and worked into a pulp without elutriation; it is then formed in moulds and dried, first in the air under sheds, and afterwards artificially, by Weber's method (page 318); the dry turf is then charred.

At Lesjöfors,[‖] in Sweden, the wet turf is triturated in mills with water, and the mass, after being formed into bricks, is dried in the open air.

*b.* **Condensing Turf in the Wet Way by means of Pressure.**—The opinions on the method of pressing freshly cut turf, which are entertained by the different investigators, differ widely; this, however, may be explained by the peculiar behaviour of the various kinds of turf. Whilst more or less favourable results are obtained in the treatment of the light fibrous turf, the earthy kinds present great difficulties, as the resistance of the water breaks the strongest machines, and fine particles of turf are also pressed out along with the water.[§] The younger kinds of turf are, therefore, alone adapted for this method, as they lose part of their water, and attain a smaller volume, a more regular shape, and more consistency. It is an advantage not to press more than 20 or 30 per cent of water from turf containing from 70 to 90 per cent, for if attempts are made to extract a greater quantity, although the expenses of the manipulation of pressing will not increase in the direct proportion of the quantity of water that has been pressed out, still the progression of the power required, and the outlay of time and labour necessitated, will be enormous, and will perfectly outbalance the advantage obtained. Pressed turf dries quicker in favourable weather than cut turf, but, on the other hand, it absorbs, in proportion, a larger quantity of moisture in rainy weather. It is best to dry pressed turf by artificial heat. The heating power of turf does not increase in direct proportion with the degree at which the turf has been pressed; experiments have shown that turf which has been strongly pressed, and has a specific gravity exceeding that of water, is, in its heating power, from 5 to 10 per cent inferior to other kinds of prepared turf, which had a specific gravity of 0·9 at the very highest; both kinds had the same degree of dryness. On this point, pressed turf behaves similarly to elutriated turf, and for this reason, namely, that the pressed pieces of turf, when suddenly put into a strong fire, superficially undergo a rapid decomposition owing to the hardness of their surface, while the air cannot penetrate into the interior of the pieces, and consequently a part of the rapidly evolved combustible gases escapes without being burnt. It is an erroneous opinion that, in pressing, larger quantities of soluble components of turf are pressed out; this may be the case with the very fine particles, but even this may be counteracted and the loss reduced to a minimum by pressing the turf in cloth.

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[*] VOGEL, der Torf. München, 1859, p. 88.

[†] B. u. h. Ztg., 1858, p. 342.

[‡] DINGL., Polyt. Journ., lii., Hft. 4, p. 272. Polyt. Centr., 1860, No. 2.

[‖] TUNNER'S LEOB. Jahrb., 1860, p. 95.

[§] POLENZ, Beschreibung der patentirten Torfpresse, 1836. ERESBY, das Pressen des Torfs, und die dabei angewandten Maschinen, 1839. DINGL, iii., 42; lxvii, 34. Bgwkfd., iv., 155. 167, 193, 465; v., 300; vi., 92, 93; vii., 92, 426; viii., 112; ix., 193, 541. B. u. h. Ztg., 1846, p. 586; 1859, p. 66; 1860, p. 244.

**Mannhardt's Method.**—By this method,* which has recently given rise to great expectations, the freshly cut turf is made to pass between rolls, 6 feet long, in which operation it loses 60 per cent of its water, and forms thin plates, which can easily be dried.

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* Polyt. Centr., 1859, p. 869. DINGL., Bd. 152, p. 238.

**Lithuanian Method.**—This method, employed in Lithuania,* is very simple and inexpensive. The turf is ploughed, and divided by being frequently turned, and, when air-dried, it is pressed into cast-iron moulds by means of a rammer weighing 2 cwts. This pressed turf, and the charcoal produced from it, are said to perfectly replace mineral coal.

*c.* **Condensing Turf in the Dry Way by means of Pressure.**—This principle was first introduced by Mr. Gwynne, in London, and has also been employed at Haspelmoor in Bavaria. It consists in dividing the dried turf, and pressing it at such a temperature that a partial carbonisation takes place, thus evolving tar, which serves as a cement. The material, however, attains sufficient consistency without the formation of tar. Gwynne dries the turf in a centrifugal machine, and then crushes it into a pulp, which is freed from water by higher temperature; the turf is afterwards ground in mills, and condensed in presses, which are heated with steam.

The resulting product, namely, solidified peat, is said to have a specific gravity of 1·14, and its heating power to amount to three-fifths of that of the best mineral coal.

Exter has introduced Gwynne's method at Haspelmoor,† with various modifications. The turf is raised by the operation of ploughing, and the process of drying is promoted by harrowing and turning the turf several times; the air-dried divided turf is now dried in rotating sieves of wire, by means of hot air, and is then pressed in eccentric presses, which are set in motion by steam power. The resulting bricks are 9½ inches long, 3 inches broad, and ¾ or 1 inch thick; they weigh from 12½ to 20 ounces, and their original volume is reduced to one-fifth; 1 cubic foot weighs from 75 to 86 lbs.

The following are the advantages of this method:—The turf may be rendered as dense as mineral coal, which facilitates its transport; one part by weight of coke may be replaced by less than two parts by weight of pressed turf; the operation of drying is not interrupted by the weather, and may be effected even in winter. On the other hand, this kind of pressed turf is not fit for carbonisation, as in this operation it will disintegrate.

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* Allgem. B. u. h. Ztg., 1859, No. 26.

† B. u. h. Ztg., 1858, p. 295; 1859, p. 7.

At the iron works at Weyherhammer, in Bavaria, the iron blast furnaces are carried on with a mixture of two-thirds of charcoal and one-third of unpressed turf, and, according to Scheerer,* it was only possible to increase the proportion of pressed turf to half of that which was not pressed, as otherwise an irregular process took place.

Although it is possible to condense the best turf so as to have the specific gravity of mineral coal (1·3 or 1·4), and also to reduce the amount of water in turf to 5 or 10 per cent, still it is impossible, with pressed turf, to produce the quantity of heat which is yielded by an equal part in weight of mineral coal, because the latter is richer in carbon and hydrogen. As the heating power of both kinds of fuel stands in the proportion of about 1 to 1·4 or 1·5, from 40 to 50 per cent more in weight, of pressed turf than of mineral coal, would be required to produce the same effect. The operation of pressing turf is also liable to increase the percentage of phosphorus.

*d.* **Condensing Turf by means of Centrifugal Power.**—This method is free from many of the difficulties offered by the operation of pressing, and rapidly produces a compact mass fit for further treatment; but the attempts which have been made to construct an apparatus admitting of an easy charging and discharging, have not been successful. The best apparatus of this kind is that constructed by Hebert, at Rheims.†

The adaptability of turf likewise depends on the amount and nature of the ash-forming components. The amount of ash varies between ½ and 30 per cent, and injures the inflammability of the impure kinds of turf, which contain a large quantity of it; the ash gives rise to the formation of a viscous slag, which frequently impairs the process, chiefly on account of the amount of phosphorus and sulphur it contains. The sulphur is partly contained in the ash as sulphuric acid combined with lime, and partly as sulphide of iron. An amount of phosphorus and sulphur is less injurious when the turf is employed in reverberatory furnaces, where a direct contact with the melting product does not take place.

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* B. u. h. Ztg., 1859, No. 2, p. 15.

† Vogel, der Torf. München, 1859, p. 83.

On elutriating turf, part of the inorganic admixtures may be removed, but not alumina.

**The Use of Turf.**—Air-dried turf, if it does not contain too large an amount of ash, is well adapted for those firings which require a moderate continued temperature, such, for example, as those for heating boilers and blast, and for cupelling raw lead, &c. Turf in raw and carbonised state is also employed, together with other fuel, in iron blast furnaces.* At Ransko in Bohemia, for instance, as much as 75 per cent of turf is used, and at Weyherhammer in Bavaria about one-third of the fuel consumed is turf. Although good turf contains the carbon in a more concentrated form than wood, its application in iron blast furnaces is more difficult, and generally more expensive, than that of the latter fuel. The most important use to which turf is applied, is in the puddling and re-heating of iron; when employed for this purpose it is previously transformed into combustible gas. The large puddling works at Buchscheiden and Freudenberg in Carinthia, are entirely based upon the application of turf. Turf is less applicable in lead cupola furnaces;† in a kiln-dried state it has also been used in the Hartz for puddling iron.‡

Generally speaking, the application of turf in cupola furnaces has its disadvantages, for the reason that it is too friable, and frequently contains too large an amount of ash. Irregularities in the process are induced by the strong contraction which turf undergoes on being carbonised, and the carbonisation absorbs a large quantity of heat which is lost to the process.

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* Bgwkfd., i., 375, 476; iii., 189, 315, 365; iv., 412; vi., 285; viii., 263, 321. LAMP., Fortschr., 1839, p. 46. KARST., Arch., vi., 217. DINGL., lxv., Hft. 6; xlvi., 202; lix., 470; cxi., 318. ERDM., J. f. ök. u. techn. Chem., xii., 337. B. u. h. Ztg., 1843, pp. 441, 736, 832; 1845, pp. 297, 337; 1843, pp. 441, 731; 1850, p. 145; 1851, p. 427; 1856, p. 375; 1857, pp. 197, 195. TUNNER'S Jahrb., 1854, p. 236; 1857, p. 131.

† KERL, Oberharzer Hüttenprocesse, 1860, p. 239.

‡ Bgwkfd., xiii., 39; xvi., 430. B. u. h. Ztg., 1844, p. 379; 1849, p. 81. DINGL., cxxxi., 153; cxxxii., 272.

Vogel considers the common lighter kinds of turf of 0·25 or 0·35 specific gravity, and containing from 25 to 36 per cent of water, to be inferior as fuel to the most inferior kinds of mineral and brown coal, and they can have little advantage over wood, except when their price is very low.

The better kinds of turf, even if containing 25 per cent of water, surpass the common air-dried wood in heating power, but only a few kinds of very superior turf approach in their effect the medium kinds of mineral coal. Turf that has been well prepared and dried, can, in many cases, compete with the other species of fuel.

It is always the amount of water which chiefly influences the heating power of turf, and a few per cents of water are sometimes sufficient to impair the results of combustion with turf, which otherwise is of good quality. It is, therefore, difficult to calculate the value of turf. When it is bought by weight, not only is the amount of water paid for, but the heating power is also impaired, and when bought by volume, it is the inferior kinds of turf which are the most voluminous.

Turf, in bricks of a certain size, and a certain degree of dryness, may be bought by the number of bricks, a mode which is sufficiently safe in practice. When wishing to compare the effect of various kinds of turf, it will be requisite to know the relative weight of each sort after having expelled all the water, and also to ascertain its amount of ash. For practical metallurgical purposes, it will not here be necessary to take into consideration those influences which a large amount of ash exerts in the process of combustion, or those differences which consist in the variable composition of turf itself.

The following table shows the heating power of turf, which depends less on the amount of ash than on that of water:—

| | Heating Power.<br>Absolute. | Heating Power.<br>Pyrometric. |
|---|---|---|
| Turf (not perfectly air-dried) containing 30 per cent of hygroscopic water and 10 per cent of ash | 0·37 | 1575° C. |
| Best air-dried turf, containing 25 per cent of hygroscopic water and no ash | 0·47 | 1750° C. |
| Kiln-dried turf, without hygroscopic water, and containing 15 per cent of ash | 0·55 | 1975° C. |
| Best kiln-dried turf, without hygroscopic water and without ash | 0·65 | 2000° C. |

According to these results, the *absolute heating power* of the best air-dried turf is a little inferior to that of kiln-dried wood, but in kiln-dried turf the absolute heating power is superior to that of kiln-dried wood. The *specific heating power*, which depends on the amount of water and ash, and the state of compactness in the best kinds of turf, is on an equality with that of air-dried wood, and, in some cases, surpasses it.

**The Pyrometric Heating Power** of moist turf containing ash is inferior to that of air-dried wood, but in kiln-dried turf the pyrometric heating power is greater than in kiln-dried wood.

According to Berthier,* the following results were obtained from peat:—

| Sources of the Peat. | Pounds of Water heated by 1 lb. of Peat from 0° to 100° C. |
|---|---|
| From Troyes | 18·1 |
| ,, Department de la Somme | 27·9 |
| ,, ,, de la Marne | 29·2 |
| ,, ,, de la Vosges | 34·9 |
| ,, ,, des Landes | 34·6 |

Peat obtained from the Bog of Allen (Ireland) gave, according to Griffith—

| | Pounds of Water heated from 0° to 100° C. |
|---|---|
| Upper peat | 62·7 |
| Lower peat | 56·6 |
| Pressed peat | 28·0 (?) |

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* Ure's Dictionary of Arts and Mines, vol. ii., p. 405.

Winkler gives 26·9 as the evaporative power of the worst peat from the Erzgebirge in Saxony, and 42·6 as that of the best.

The different kinds of turf reduce of lead—

| | Parts in Weight. |
|---|---|
| French turf, according to Berthier . . . . | 8—15·3 |
| Irish turf, ,, Griffith . . . . | 25—27·0 |
| ,, (pressed) ,, ,, . . . . | 13·7 |
| Turf from the Erzgebirge, according to Winkler[*] . . . . . . . . . . . . . | 11·9—18·8 |
| Turf from the Upper Hartz, containing from 0·5 to 5 per cent of ash . . . . . . . . | 11—18·0 |

**Practical Results.**—The following results have been obtained concerning the application of turf:—

1. Karmarsch ascertained that the absolute heating power of the different kinds of turf, compared to pine wood, stands in the following proportion:—

| lbs. | | lbs. | |
|---|---|---|---|
| 1000 | yellow turf | = 946 | air-dried pine-wood. |
| 1000 | brown ,, | = 1076 | ,, ,, |
| 1000 | earthy ,, | = 1040 | ,, ,, |
| 1000 | pitch ,, | = 1107 | ,, ,, |
| **Cubic Feet.** | | **Cubic Feet.** | |
| 1000 | yellow ,, | = 332 | pine wood. |
| 1000 | brown ,, | = 897 | ,, |
| 1000 | earthy ,, | = 1446 | ,, |
| 1000 | pitch ,, | = 1843 | ,, |

These results closely correspond with those obtained by the Society for Promoting Industry in Prussia.

2. On the Dublin steamers, it has been observed that 51 lbs. of good turf evaporate 1 cubic foot of water, and 7·61 lbs. replace 1 lb. of coke.

3. According to Williams,[†] two parts by weight of turf are equal to one part of mineral coal, and the former are consumed in the fire-place in half the time required for the latter. In burning turf, the grate bars must lie deeper, and fresh air must be admitted behind the fire-bridge.

4. According to Karsten, in boiling processes, four parts by

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[†] Winkler, über Zusammensetzung, Werthverhältnisse und Verkohlungsfähigkeit der vornehmsten Torfsorten des sächsischen Erzgebirges, 1840.

[*] Dingl., lxxii., 31, 229, 289; lxxiv., 107. Polyt. Centr., 1846, p. 301.

volume of turf replace one part of mineral coal, and 2½ lbs. replace 1 lb. of coal.

5. Rose states that 1000 bricks of best elutriated turf replace 72 cubic feet of fir-wood, and a little more than 54 cubic feet of hard wood.

6. According to Winkler, 1800 lbs. of floated wood are equal in effect to 1294 lbs. of best turf, containing 1 per cent of ash, 54·2 per cent of carbon, and 43·8 per cent of water.

7. Eiselen ascertained that 108 cubic feet of fir-wood are equal in effect to—

154 cubic feet of turf of best quality.
203 " " medium "
305 " " worst "

8. According to Heeren, 144 cubic feet of beech wood replace 570 cubic feet of the lightest turf, each cubic foot weighing 8 lbs., 270 cubic feet of medium turf weighing 10 lbs. each, and 150 cubic feet of best turf, 12 lbs. each; 144 cubic feet of pine wood replace 460, 220, and 125 cubic feet respectively.

9. Brix ascertained that 100 lbs. of turf, containing from 24·5 to 38·3 per cent of water, evaporated from 281 to 343 lbs. of water.

10. According to Vogel, air-dried fibrous turf from the neighbourhood of Munich,* containing from 25 to 30, 20, and from 5 to 10 per cent of water, evaporates 3·0—3·5, 4·0—4·5, and 5·0—5·5 parts of water respectively. Good turf prepared by machines, when air-dried and having a specific gravity of 0·6, evaporates from 4·5 to 6·0 of water, and from 5·0 to 5·5 parts of water when perfectly dry. Well-pressed turf, containing from 10 to 15 per cent of water, and having a specific gravity of 1·15, evaporates from 5·8 to 6·0 parts of water.

11. On the Bavarian railways, 10 cubic feet of wood, 17·9 cubic feet of turf, and 67·7 lbs. of coke are consumed, on an average, for one hour's drive.

12. The following table contains Tunner's† theoretical

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* B. u. h. Ztg., 1858, p. 351. Oesterr. Ztschr., 1857, No. 44.

† TUNNER'S LEOB., Jahrb., 1860, p. 113.

calculation, comparing different kinds of turf with wood and charcoal:—

| | Heating Power. | |
|---|---|---|
| | Absolute. | Pyrometric. |
| Dry turf without ash . . . . . . | 0·65 | 2210° C. |
| ,, containing 4 per cent of ash | 0·63 | 2200° C. |
| ,, ,, 12 ,, | 0·58 | 2180° C. |
| ,, ,, 30 ,, | 0·45 | 2150° C. |
| Turf containing 25 per cent of hygroscopic water . . . . . . . | 0·47 | 2000° C. |
| Turf containing 30 per cent of hygroscopic water . . . . . . . | 0·41 | 1820° C. |
| Turf containing 50 per cent of hygroscopic water . . . . . . . | 0·27 | 1600° C. |
| Dry wood without hygroscopic water | 0·47 | 2000° C. |
| Wood containing 20 per cent of hygroscopic water . . . . . . . | 0·36 | 1800° C. |
| Dry charcoal without hygroscopic water . . . . . . . . . . . | 0·97 | 2450° C. |
| Charcoal containing 12 per cent of hygroscopic water . . . . . . | 0·85 | 2380° C. |
| Charcoal containing 18 per cent of hygroscopic water . . . . . . | 0·87 | 2340° C. |

In this calculation it has been supposed that the turfy substance is composed of—

| | |
|---|---|
| Carbon . . . . . . . | 60·00 per cent |
| Hydrogen . . . . . . | 6·22 ,, |
| Oxygen . . . . . . . | 33·78 ,, |

and that wood contains 1 per cent of ash, and charcoal 3 per cent.

13. In Ure's "Dictionary," vol. iii., page 381, it is stated that, notwithstanding its extreme variations, we may yet establish the ordinary constitution of turf with sufficient certainty for practical use; and from the average specimens of turf selected from various localities, the following results have been obtained:—

The caloric power of dry turf is about half that of coal; it yields, when ignited with lead, about fourteen times its weight of lead. The power is, however, immensely diminished in ordinary use by the water which is allowed to remain in its texture, and from which, on account of the spongy character of its mass, it is very difficult to free it. There is nothing which requires more attention than the collection and preparation of turf; indeed, for practical purposes, this valuable fuel is absolutely spoiled by the manner in which it is now prepared in Ireland. It is cut in a wet season of the year, and, while drying, is left exposed to the weather; hence, in reality, it is not dried at all. It is very usual to find the turf of commerce contain one-fourth of its weight of water, although it then feels dry to the touch. But let us examine what affects the caloric power. 1 lb. of dry turf will evaporate 6 lbs. of water; now, in 1 lb. of turf, as usually found, there are ¾ lb. of dry turf, and ¼ lb. of water. The ¾ lb. can only evaporate 4½ lbs. of water; but out of this it must first evaporate the ¼ lb. contained in its mass, and hence the water, boiled away by such turf, is reduced to 4¼ lbs. The loss is here 30 per cent, a proportion which makes all the difference between a good fuel and one almost unfit for use. When turf is dried in the air under cover, it still retains one-tenth of its weight of water, which reduces its caloric power 12 per cent; 1 lb. of such turf evaporates 5⅓ lbs. of water. This effect is sufficient, however, for the great majority of objects; the further desiccation is too expensive and too troublesome to be used, except in special cases.

The characteristic fault of turf as a fuel is its want of density, which renders it difficult to concentrate, within a limited space, the quantity of heat necessary for many operations. The manner of heating by turf is, indeed, just the opposite to that by anthracite. The turf yields a vast body of volatile, inflammable ingredients, which pass into the flues and chimney, and thus distribute the heat of combustion over a great space, whilst in no one point is the heat intense. Hence for flaming fires turf is applicable; there is, however, as experiments made on Dartmoor prove, some liability to that burning away of the metal which may arise from the local intensity of turf. If requisite, it is quite possible to obtain a very intense heat with turf.

It has been the object of many to remove the porosity and elasticity of turf, so that it may assume the solidity of coal, and, for this purpose, mechanical and other processes have been proposed. It has been found that the elasticity of the turf fibre presents great obstacles to compression, and the black turf, which is not fibrous, is of itself sufficiently dense.

## Turf Charcoal.

Turf charcoal[*] has not obtained a general application in practice, although numerous attempts have been made, from time to time, to bring it into use for smelting iron, and other metallurgical processes. As far back as 1712, we were told by Carlowitz, that peat was charred in piles or stacks as wood is. Vogel informs us that, in 1735, peat charcoal was made in the Hartz. Numerous experiments have been made on the Continent to produce a charcoal from peat which should answer the requirements of metallurgy; none, however, appear to have been entirely successful. Within the last few years, experiments have been made in Ireland to smelt the hæmatite iron ore of Cumberland with peat charcoal. The exact results of these experiments have not been made known, but it is certain they did not promise to be commercially successful, and the idea has long since been abandoned.

Peat is usually charred by methods similar to those employed for the carbonisation of wood.

The most economical carbonisation of turf is that carried on in heaps, in the same manner as that of wood. The sods must be regularly arranged, and laid as close as possible; they are the better for being large, 15 inches long, by 6 broad and 5 deep. The heaps, built hemispherically, should be smaller in size than the heaps of wood usually are. In general, 5,000 or 6,000 large sods may go to the heap, which will thus contain 1,500 cubic feet. The mass must be allowed to heap more than is necessary for wood, and the process requires to be very carefully attended to, on account of the extreme combustibility of the charcoal. The quantity of charcoal obtained in this mode of carbonisation is from 25 to 30 per cent of the weight of dry turf.

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[*] Ure's Dictionary of Arts and Mines, vol. iii., p. 382. Bgwkfd., i., 313, 338, 374; iii., 24; iv., 193, 210; v., 428; vi., 491; vii., 395, 410; x., 173, 255, 303; xii., 320, 366, 635. Dingl., lxxxvi., 289; lxxxiii., 347; cxv., 418. Erdm., J. f. pr. Chem., ii., 10; xiv., 408. B. u. h. Ztg., 1844, p. 43; 1851, p. 185; 1854, p. 167. Polyt. Centr., 1838, p. 449. Jahrb., f. d. säschs. Berg- u. Hüttenmann., 1827, p. 193; 1840, p. 86. Karst., Arch., 1 R., vi. 427. Mittheilungen des Gew.-Ver. f. d. Königr.: Hanover, 1846, p. 71. Vogel, der Torf., 1859, p. 105.

For many industrial uses, the charcoal so prepared is too light, as, generally speaking, it is only with fuel of considerable density that the most intense heat can be produced; but by coking compressed turf the resulting charcoal may attain a density of 1·040, which is far superior to wood charcoal, and even equal to that of the best coke made from coal. As to caloric effects, turf charcoal is about the same as coal coke, and little inferior to wood charcoal.

It is especially important, in the preparation of charcoal from turf, that the material should be selected as free as possible from earthy impurities, for all such are concentrated in the coke, which may be thereby rendered of comparatively little value. Hence, the coke from surface turf contains less than 10 per cent of ash, whilst that of dense turf of lower strata contains from 20 to 30 per cent, and even more. This latter quantity might render it altogether unfit for practical purposes. 100 lbs. of dry peat, according to Messrs. Ronalds and Richardson, leave 21 lbs. of ash, and produce 47 lbs. of charcoal; those 47 lbs. of peat charcoal contain, therefore, 21 lbs., or 45 per cent of ash.

When turf is charred by being heated in close vessels, loss is avoided, but it is expensive, and there is no compensation in the distilled liquors, which do not contain acetic acid in any quantity. The tar is often small in proportion, hence the charcoal is the only valuable product. Its quantity varies from 30 to 40 per cent of dry turf. The products of the distillation of 1157 lbs. of turf were found by Blavier to be—Charcoal, 474 lbs., or 41 per cent; watery liquid, 226 lbs., or 19·3 per cent; gaseous matter, 450 lbs., or 39 per cent; and tar, 7 lbs., or 6 per cent; but the proportion of tar is variable, sometimes reaching 24·5 per cent when the turf is coked in close vessels.

On Dartmoor, the peat is cut by the convicts, working in gangs; and being dried, it is carefully stored in one of the old prisons. From this peat, by a most simple process, gas is made, with which the prisons at Prince Town are lighted. The illuminating power of this gas is very high. The charcoal left after the separation of the gas is used in the same establishment for fuel and for sanitary purposes, and the ashes eventually go to improve the cultivated lands of that bleak region. Attempts were made here many years since to distil the peat for naphtha, paraffin, &c., but the experiments not proving successful, the establishment was abandoned.

Experiments of a similar character have been made in Ireland, especially by a company working under the patents of Mr. Rees Reece. A Government commission made their report on these experiments.

The object being to ascertain the necessary facts regarding the products of commercial value, the following was the course pursued:—

Specimens of turf, representing the several ordinary varieties, were separately experimented on, and the results examined.

The products of the distillation were collected as—

1. Charcoal.
2. Tar.
3. Watery liquids.
4. Gases.

The relative quantities produced by 100 parts of peat were found to be—

| | Average. | Maximum. | Minimum. |
|---|---|---|---|
| Charcoal . . . . . | 29·222 | 39·132 | 18·973 |
| Tarry products . . | 2·787 | 4·417 | 1·462 |
| Watery products. . | 31·378 | 38·127 | 21·819 |
| Gases . . . . . . | 36·616 | 57·746 | 25·018 |

The peats yielding the above proportions of products have been found to contain, previous to distillation, as dried in the air, a quantity of hygrometric moisture, and to yield a proportion of ashes in 100 parts, as follows:—

| | Average. | Maximum. | Minimum. |
|---|---|---|---|
| Moisture . . | 19·71 | 29·56 | 16·39 |
| Ash . . . . | 3·43 | 7·90 | 1·99 |

The following tables give the percentages of carbon, &c., in different varieties of peat:—

| | Vulcaire, near Abbeville. | Long, near Abbeville. | Champ de Fer, near Framont. |
|---|---|---|---|
| Carbon . . . | 60·40 | 60·89 | 61·05 |
| Hydrogen . . | 5·90 | 6·21 | 6·45 |
| Oxygen . . . | 33·64 | 32·90 | 32·50 |
| Ash, in 100 parts | 5·58 | 4·61 | 5·33 |

| | Friesland. Compact Turf. | Friesland. Surface Turf. | Holland. |
|---|---|---|---|
| Carbon . . . | 59·42 | 60·41 | 59·27 |
| Hydrogen . . | 5·87 | 5·57 | 5·41 |
| Oxygen . . . | 34·71 | 34·02 | 35·32 |
| Ash, in 100 parts | 3·80 | 0·91 | 14·25 |

The following results were obtained by Sir Robert Kane, from peats from the Irish bogs, and published in the "Proceedings of the Royal Irish Academy:"—

| | Kilbeggan, in Westmeath. | Kilbaha, in Clare. | Cappoge. in Kildare. |
|---|---|---|---|
| Carbon . . . | 61·04 | 51·13 | 51·05 |
| Hydrogen . . | 6·67 | 6·33 | 6·85 |
| Oxygen . . . | 30·45 | 34·48 | 39·55 |
| Ash . . . . | 1·83 | 8·06 | 2·25 |

The determination of charcoal and volatile matters found in peat, in the following table, are—1, from Rue, in the Department of Somme; 2, from Abbeville, by Berthier; 3, from Vaucluse, by Diday; 4, from Sécheral, by Sauvage; 5, from Kildare; 6, from Kilbeggan; 7, from Kilbaha; and 8, from Cappoge, by Sir Robert Kane:—

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| Charcoal . . . | 21·0 | 23·0 | 17·3 | 22·0 |
| Volatile matter. . | 72·0 | 72·2 | 65·3 | 39·2 |
| Ash . . . . . | 7·0 | 4·8 | 17·4 | 8·3 |

| | V. | VI. | VII. | VIII. |
|---|---|---|---|---|
| Charcoal . . . | 23·82 | 22·67 | 19·14 | 23·65 |
| Volatile matter. . | 73·63 | 75·50 | 72·80 | 70·10 |
| Ash . . . . . | 2·55 | 1·83 | 8·06 | 6·24 |

The several products of the distillation were then specially examined. Sir Robert Kane (Director of the Museum of Irish Industry) and Dr. Sullivan conducted the examination, and the following is an extract from their report, as far as it relates to the employment of turf for metallurgical purposes:—

"The investigation proved satisfactorily that the peat, by destructive distillation in close vessels, yielded several products that were identical, or closely analogous, to those afforded in the distillation of wood or coal. The process in close retorts, however, was not at all what had been proposed, nor was it economically practicable for commercial purposes; this being the case, it was necessary to determine whether the same varieties of peat, distilled in a blast furnace, with a current of air, so that the heat necessary for the distillation was produced by the combustion of the peat itself, would furnish the same products, and whether in greater or in less quantities than in the process in close vessels.

"For this purpose, the cylinder, which, in the former series of experiments, had been set horizontally in the furnace, was placed vertically, and was surrounded by brickwork, its mouth projecting a little at the top, so that the tube for conveying away the products of the distillation passed horizontally from the top of the brickwork casing to the condensing apparatus. Near the bottom of the cylinder, the brickwork left a space, where the cylinder was perforated by an aperture 1¼ inches in diameter, to which the tube of a large forge bellows was adapted. The arrangement thus represented nearly the construction of an iron cupola. The cylinder being charged with peat, of which some lighted fragments were first introduced, and the blast being put on, the combustion spread, and the cover of the cylinder being screwed down, the distillation proceeded; the products passing with the current of air into the series of condensing vessels, and the gases and air being finally conducted by a waste pipe to the ash-pit of a furnace, where they were allowed to escape.

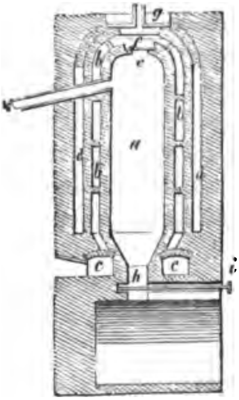
By this means, a satisfactory representation of the condition of air-blast distillation of peat, which has been proposed as the commercial process, was obtained on a moderate scale."

Sir Robert Kane, amongst others, draws the following conclusions:—

"That the economy introduced in the treatment of the tarry and watery products of pit distillation consists partly in the utilisation of the waste gases from the condensing pipes, so as to supersede the use of other fuel, by burning the gas in jets under the steam boilers, evaporating pans, &c., and that this economy is of the most important character, and appears more than any other condition to influence the probable success of the manufacture on the large scale; that, therefore, the amount of advantage derived from similar employment of gases in iron-smelting works, will deserve careful comparison, and that it will be necessary particularly to take into account the difference of combustibility of gaseous mixtures when very hot, as when from an iron furnace, and when quite cold, as from the condensing apparatus of a peat blast furnace."

At Crouy, upon the Ourcq,* near Meaux, there is a well constructed kiln for making turf charcoal. It closely resembles a tar-kiln, and is represented in Fig. 73. *a* is the cylindrical coking place, whose surrounding walls are heated by the flame which passes through the intermediate space, *b*. The place itself is divided by partitions of fire tiles into three stages, through the apertures of which the flame of

FIG. 73.



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* URE'S Dictionary of Arts and Mines, vol. i., p. 686.

the fire, *c*, *c*, rises, and heats the exterior of the coking apartment. In order to confine the heat, there is in the inclosing walls of the outer kiln a cylindrical hollow space, *d*, where the air is kept stagnant. Through the apertures left in the upper end at *e*, the turf is introduced ; they are then shut with an iron plate, *f*, which is covered with ashes and sand. The fire-place opens above this aperture, and its outlet is provided with a movable iron cover, *g*, in which there is a small hole for the issue of the gases. The sole of the kiln consists of a cast-iron slab, *h*, which may be raised by means of a hook, *i*, upon it. This is drawn back after the carbonisation is completed, whereupon the charcoal falls from the coking space into a subjacent vault. The volatile products are carried off by the pipe, *k*, and led into the condensing cistern, the gases escaping to the fire-place, where they are burned. The iron slab is protected from the corrosion of the acid vapours by a layer of coal ashes.

In 1849, Mr. Vignoles patented a process for charring peat by steam superheated to the melting point of tin or lead. Pulped peat is thrown in mass into a cylindrical drum-shaped vessel, divided, if necessary, into compartments, which is caused to revolve with great rapidity upon an axis—the velocity requisite being such as shall drive off the water or other fluid from the solid parts of the peat or turf by centrifugal force. When all the water is removed from the peat by this process, and it is in a coherent mass, it is removed and moulded into blocks. These blocks are put into large cylindrical iron vessels, into which steam at from 45 to 60 lbs. pressure per square inch is admitted, after a process of superheating, by traversing iron tubes heated to bright redness. This process, although strongly recommended, has never come into practical use.

Rogers adopted in Ireland a system of drying and carbonising peat, which was for some time carried forward with much promise of success. Green produced a draught of hot air through a drying house by means of chimneys and fires. He then distilled the dry peat in wrought-iron cylinders, similar to those employed in making illuminating gas.

Notwithstanding all the attempts which have been made to utilise peat charcoal, not one process has been carried out (1866) on a large scale.

**Practical Results.**—According to Scheerer, the most inferior kind of turf charcoal, containing 10 per cent of hygroscopic moisture and 56 per cent of ash, has an absolute heating power of 0·85, and a pyrometric heating power of 2050° C., while the best turf charcoal containing 10 per cent of hygroscopic water and 4 per cent of ash, has 0·33 and 2350° C. respectively. The absolute and specific heating power of turf charcoal is, therefore, nearly equal to that of wood charcoal.

Berthier states that turf charcoal reduces from 17·7 to 26 parts of lead, and heats from 40·1 to 58·9 parts of water of 0° up to 100° C. According to later experiments made by the Society for Promoting Industry in Prussia, 1 lb. of turf charcoal, containing, on an average, 5·4 per cent of water and 3·40 per cent of ash, converts 6·68 lbs. of water of 0° C. into steam of from 110° to 115° C., and turf charcoal, containing no water and 3·59 per cent of ash, converts 7·10 lbs. of water into such steam.

According to Stöckhardt,* equal quantities of fuel evaporate the following quantities of water:—

| | |
|---|---|
| Charcoal | 189 |
| Mineral coal from Saxony | 179 |
| Turf charcoal | 170 |
| Turf from Saxony | 102 |
| Pine wood | 81 |

100 lbs. of charcoal may, therefore, be replaced by—

| | lbs. |
|---|---|
| Mineral coal | 105 |
| Turf charcoal | 113 |
| Turf in bricks | 188 |
| Pine wood | 234 |

Turf charcoal has also been employed for the manufacture of artificial fuel.†

Concerning its application, Overmann‡ states as follows:—

“ Peat charcoal has peculiar advantages for welding steel and iron, and excels all other fuel in this respect. It facilitates the welding of steel to steel, or steel to iron, or working of small iron, and causes the adhesion of the metal. It is impossible to account for this peculiar effect, except by the composition of its ash, which consists chiefly of lime, clay, oxide of iron, silica, a large quantity of phosphate of lime, and a little gypsum; these substances form a very fusible slag. It is the phosphorus which, by combining with iron or steel, causes it to be fusible and suitable for welding. This peculiarity of the ash of turf is injurious to pig-iron, which is cold-short in all cases when smelted by turf, but it may be advantageous in smelting lead ores, particularly those refractory lead ores which are smelted for silver."

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* Bgwkfd., ii., 553.

† Ibid., iv., 210; x., 253.

‡ OVERMANN'S Treatise on Metallurgy, p. 374.

## BROWN COAL.

Brown coal* is an older formation than turf, but it is of later date than the true carboniferous strata belonging to the tertiary period.

According to the physical properties and the date of formation, both of which are connected, brown coal may be classified thus:—

1. **Lignite**, that is to say, fossil, fibrous wood, which has undergone one of the changes leading towards the formation of coal, but still retains the vegetable texture, and has a dark colour; its specific weight is 1·5.

If wood is buried in moist earth, carbonic acid is produced from the elements of the wood, which is changed into either lignite or brown coal. These two substances differ chemically from each other. Lignite yields, by dry distillation, acetic acid and acetate of ammonia, whereas coal produces only an ammoniacal liquor. Woody fibre gives rise to acetic acid; lignite must, therefore, still contain undecomposed woody fibre.

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* ERDM., Journ. f. pr. Chem., x., 47. Bgwkfd., vii., 449; x., 448; xiii., No. 23; xv., 343. Polyt. Centr., 1852, p. 356. B. u. h. Ztg., 1852, pp. 81, 107. Ztschrft. f. d. Berg- Hütten- und Salinenwesen in Preussen, 1853, i., 82. DINGL., cxvi., 103, 113. LIEBIG, Jahresber., 1849, p. 708. KNAPP, Chem. Techn., i., 16. BISCHOFF, Chem. u. Phys. Geologie, ii., 1755. URE's Dictionary of Arts and Mines, vol. i., 495; vol. ii., 870.

The following table gives the composition of several well-known lignites :—

| | Carbon. | Hydrogen. | Oxygen and Nitrogen. | Earthy Matter. | Chemist. |
|---|---|---|---|---|---|
| From Uttweiler . . . | 77·9 | 2·6 | 19·5 | 1·0 | Karsten. |
| „ Hungary . . . | 67·3 | 4·3 | — | 0·8 | Nendtwich. |
| „ the Rhone . . . | 72·2 | 4·9 | 20·1 | 1·8 | Regnault. |
| „ Meissner . . . | 68·6 | 5·9 | 19·0 | 2·3 | Gräger. |
| „ Bovey Heathfield | 67·9 | 5·8 | 24·8 | — | Vaux. |

2. **Bituminous Wood,** which more nearly approaches mineral coal than wood.

3. **Earthy Brown Coal,** which is more or less darkish brown, and contains a considerable amount of ash. Its specific gravity is 1·3; it sometimes contains roots, leaves, twigs, and pieces of wood in admixture. This earthy kind of brown coal is now and then pressed into moulds, so as to form bricks, which then are dried.

4. **Common Conchoidal Brown Coal.**—In this kind of brown coal all organic structure has disappeared, and some varieties are called pitch coal, from their strong resemblance to the well-known jet, from which they differ, however, in having a less deep black colour and a fainter lustre.* Brown coal becomes transformed into pitch coal by merely drying it in the atmosphere.† Brown coal differs from mineral coal in showing a red streak when scratched with a sharp instrument, and in producing a brown solution when treated with caustic potash, neither of which circumstances occur with mineral coal. When brown coal is ignited by means of a blowpipe, it continues to burn, which also constitutes a difference between it and mineral coal. The specific gravity of the conchoidal variety is 1·2.

The following are the chief brown coal mines of Europe:—

Throughout the German Zollverein, in the year 1863, the brown coal produced in 843 collieries yielded 109,189,899 cwts., valued at 5,061,241 thalers.

A variety of brown coal, called the paper coal of Rott, near Bonn, and of Erpel on the Rhine, contains numerous remains of fresh-water fish, *Leuciscus papyraceus*, and of frogs, *Palaeophrygnos grandipes*. The ashes of this coal are also rich in infusorial remains.

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* Polyt. Centr., 1849, p. 1146. Leonh., Jahrb., 1849, p. 526.

† Bgwkfd., xii., 285.

In Saxony, much of the brown coal is collected on or near the surface. This is much finer than that from the pits, and is made up like peat in moulds in the shape of bricks.

Bohemia produces a large quantity of brown coal, 306,345 tons of which were brought, in 1864, into Berlin market.

At Steieregg in Southern Styria, brown coal occurs in the form of a basin, and has been opened out over a distance of more than two miles. The coal, from 8 to 16 feet thick, is of good quality. It contains from 9 to 14 per cent of water, and leaves from 5 to 12 per cent of ash after combustion.

The following is an analysis of a variety from Oregon:—

| | |
|---|---|
| Volatile matter | 49·5 |
| Fixed carbon | 42·9 |
| Ash | 2·7 |
| Water | 4·9 |

Nassau produces *lignite*, a bituminous wood preserving the ligneous structure, *pseudolignite*, in which the woody structure is more or less obliterated, *meerkohl* (literally *sea coal*), a miry earthy coal resembling turf, and *blätterkohl* (literally *leaf coal*), a dark coloured aggregate of decomposed leaves.

Switzerland, Italy, and Greece also produce more or less brown coal.

In this country, with the single exception of the Bovey Heathfield formation, which is used in the adjoining pottery, lignite is not employed, and in America, also, brown coal is not used for metallurgical purposes.

**Chemical Composition of Brown Coal.**—The chemical composition* varies with the age of the brown coal, and according to its proportion of ash and water. The following is the average composition of the compact organic mass:—

| | Carbon. | Hydrogen. | Oxygen. |
|---|---|---|---|
| Fibrous brown coal | 60 | 5 | 35 |
| Earthy ,, | 70 | 5 | 25 |
| Conchoidal ,, | 75 | 5 | 20 |

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* ERDM., Journ. f. pr. Ch., vi., 299, 336; xiii., 108; xix., 478; xxiii., 252. Bgwkfd., xi., 145. KNAPP, Chem. Techn., i., 18.

or, supposing all the oxygen to be combined with hydrogen for the formation of water—

| | Carbon. | Hydrogen. | Water. |
|---|---|---|---|
| Fibrous brown coal | 60 | 1 | 39 |
| Earthy ,, | 70 | 2 | 28 |
| Conchoidal ,, | 75 | 3 | 22 |

The amount of ash in brown coal varies from 0·5 to about 50 per cent, but usually averages between 5 and 10 per cent. The chief components of the ash are alumina, peroxide of iron and manganese, magnesia, lime and silica, and sometimes it also contains alkalies and chlorine. It differs from the ash of turf in usually containing no phosphoric acid, instead of which a considerable proportion of sulphuric acid is frequently found in it, owing to pyrites which very often contaminate the brown coal.

The following is the amount of ash contained in brown coal from different localities :—

| | | |
|---|---|---|
| Brown coal from Bohemia . . . | 1·50— 7·0 | per cent. |
| ,, ,, Bavaria . . . | 3·40—10·0 | ,, |
| ,, ,, Hesse . . . | 0·81—15·5 | ,, |
| ,, ,, France . . . | 3·00—13·0 | ,, |
| ,, ,, Rhenish Prussia | 0·90—58·0 | ,, |
| ,, ,, Halberstadt . | 2·00— 5·0 | ,, |
| ,, ,, Brunswick . . | 7·80— 8·4 | ,, |
| ,, ,, Duingen . . . | 3·00—55·0 | ,, |

Slate and loam intermixed with brown coal may be removed by washing.

The raised coal at Prävali in Carinthia is thrown into sieves, and thus sorted. The smaller pieces of less than 1 cubic inch then fall into a gutter containing a stream of water, which conducts them to other sieves having 280 holes per square foot. In this manner the small coal of about ½ cubic size is likewise purified from slate and loam and assorted; the sieves for this purpose contain 350 holes per square foot.

The hygroscopic water in freshly raised brown coal may amount to 50 per cent, and, on an average, to 20 per cent in air-dried coal, which has, therefore, about the following composition :—

| | Carbon. | Hydrogen. | Chem. comb. Water. | Hygroscopic Water. |
|---|---|---|---|---|
| Fibrous brown coal | 48 | 1 | 31 | 20 |
| Earthy ,, | 56 | 2 | 32 | 20 |
| Conchoidal ,, | 60 | 3 | 17 | 20 |

**Employment of Brown Coal.**—Brown coal burns with an unpleasant empyreumatic odour, and produces a strongly smoking flame, which has little heating power. The length of the flame is between that of wood and of mineral coal. In heating with brown coal, the effect is produced more by the flame than by the glowing coals which remain. The injurious amount of water, which forms an integral component of brown coal, may be somewhat lessened in effect by keeping the fire-place very hot. Experience has proved that fresh brown coal is preferable to that which has been stored, as the latter, when kept for a long time, undergoes a slow combustion, even if it contains no pyrites, and thus loses in heating power; the combustion may sometimes increase so much as to ignite the coal.* Brown coal is not fit to be carried a long distance; it also disintegrates when exposed for some length of time to the air, as well as when artificially dried.† It must never, therefore, be kept long, and must be stored under shelter, and in the shade. It most cases, lignites are only artificially dried for the purpose of producing higher degrees of temperature. It has sometimes been found advantageous to compress the earthy kinds of brown coal,‡ but only the very best kinds are capable of producing a temperature of more than 2000° C.

According to Scheerer, the various kinds of brown coal produce the following heating powers:—

| Varieties of Brown Coal. | Hygroscopic Water. per cent. | Ash. per cent. | Heating Power. Absol. | Specif. | Pyrom. |
|---|---|---|---|---|---|
| Air-dried fibrous brown coal, containing | 20 | — | 0·48 | 0·55 | 1800 |
| ,, ,, ,, ,, | 20 | 10 | 0·43 | — | — |
| ,, earthy ,, ,, | 20 | — | 0·61 | 0·79 | 1975 |
| ,, ,, ,, ,, | 20 | 10 | 0·55 | — | — |
| ,, conchoidal ,, ,, | 20 | — | 0·69 | 0·83 | 2050 |
| ,, ,, ,, ,, | 20 | 10 | 0·62 | — | — |
| Kiln-dried fibrous ,, ,, | 20 | — | 0·61 | — | 2025 |

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* Bgwkfd., xiii., 355. Liebig's Jahresber., 1851, p. 733.

† Polyt. Centr., 1854, p. 185.

‡ Bgwkfd., iv., 169; xiii., 354. Neue Folge, 1 Bd., 1 Lief., p. 3 (1860). Dingl., clii., 238. Berggeist, No. 66, de 1859.

| Varieties of Brown Coal. | | | | Hygroscopic Water. per cent. | Ash. per cent. | Heating Power. Absol. | Specif. | Pyrom. |
|---|---|---|---|---|---|---|---|---|
| Kiln-dried | fibrous | brown coal, | containing | 20 | 10 | 0·55 | — | — |
| ,, | earthy | ,, | ,, | 20 | — | 0·76 | — | 2125 |
| ,, | ,, | ,, | ,, | 20 | 10 | 0·69 | — | — |
| ,, | conchoidal | ,, | ,, | 20 | — | 0·85 | — | 2200 |
| ,, | ,, | ,, | ,, | 20 | 10 | 0·76 | — | — |

According to these statements, air-dried brown coal excels kiln-dried wood in absolute and pyrometric heating power, and its specific heating power is more than twice as large as that of the best wood.

Berthier has ascertained that air-dried brown coal reduces from 14 to 25 parts of lead, and heats from 38 to 57 parts of water from 0° up to 100° C.

Although brown coal, especially the earthy varieties, has a lower heating power than mineral coal, and cannot be applied to many purposes in which the latter is advantageously employed, it still constitutes a cheap fuel for common use.

Brown coal is chiefly employed in boiling operations,* in the burning of lime and bricks, as domestic fuel, and also in metallurgical operations, either† for direct firing,‡ or for the production of combustible gases, which are used in puddling and re-heating processes. Owing to its property of crumbling when heated, and also to its frequently injurious amount of ash, brown coal is employed but little in iron blast furnaces.

According to Tunner,‖ attempts have been made to use the superior brown coal of Austria, that of Leoben, for instance, in blast furnaces together with other fuel, but it was only possible to add one-eighth or one-fourth, at the highest, to a charge of charcoal, as otherwise a considerable lowering of the temperature took place. At the foundry at Brückel in Carinthia, brown coal is used in cupola furnaces in such a manner that three charges of charcoal of 2 cubic feet each are first made, and the next charge consists of 30 lbs. of brown coal. When trying to replace every third charge of charcoal by lignite, which occurs in large quantities at Voitsberg in Styria, and Wolfsegg in Upper Austria, the cupola furnace, 12 feet high, and provided with two tuyeres, became so cool that thickly liquid iron was produced. Tunner considers the application of lignite in cupola furnaces to be possible, if a corresponding quantity of hot blast of suitable pressure be employed, if the furnace be suitably constructed, and if some lime be added in order to render the viscous slag liquid.

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* ERDM., J. f. pr. Chem., vi., 208. DINGL., xcii., 355. Bgwkfd., viii., 203, 221.

† Bgwkfd., ii., 291, 381, 396, 462, 474; xi., 309. Jahrb. f. d. sächs. Berg- und Hüttenmann, 1839, p. 106; 1840, p. 84. B. u. h. Ztg., 1844, p. 73.

‡ KARST., Arch., ii. R., xxiii., 411. Bgwkfd., vii., 26; ix., 249; xi., 309.

‖ TUNNER'S LEOB., Jahrb., vi., 186.

When brown coal is employed in salt works or for heating steam boilers, &c., step-grates must be used; by this arrangement more than 20 per cent in fuel and time were saved in Saxony when boiling down salt.*

The puddling and re-heating furnaces at Prävali in Carinthia, and those at Leoben† in Styria, are provided with step-grates for burning brown coal.

At Sauforste,‡ near Regensburg, lignite, which is artificially dried by the heat of the furnaces, is burned on horizontal and step-grates of puddling and re-heating furnaces. The same application is made of the brown coal of Wolfsegg, at Kaufing‖ in Upper Austria, where it has been proved that 44 cwts. of fresh brown coal have the same effect as 16 or 18 cwts. of good soft wood.

## Practical Results.

1. Three parts by volume have the same effect as one part of mineral coal, and, by weight, one part of mineral coal may replace 2·86 parts of brown coal.

Brown coal can only be advantageously used where it occurs in large masses close to its place of application, when the price of wood and mineral coal at those places is rather high. When brown coal is employed at some distance from the place of its occurrence, it is necessary that the price of transport be very low, as this fuel is too heavy and voluminous in proportion to its heating power.

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* ZERRENNER'S Met. Gasfeuerung, p. 218.

† TUNNER'S Jahrb., 1852, p. 246.

‡ B. u. h. Ztg., 1854, No. 36.

‖ Oesterr. Ztschr., 1857, No. 12.

2. According to Bischoff,* the fresh brown coal of the Prussian province, Saxony, contains from 31·66 to 50·7 per cent of hygroscopic water, and has a specific gravity of from 1·127 to 1·318. One ton (Prussian) of fresh brown coal weighs from 306 to 360 lbs., contains from 155 to 232 lbs. of dry coal, with from 1·83 to 30·29 per cent of ash, and evaporates, according to theoretical calculations, from 14·66 to 27·16 cubic feet of water. The real effect is, however, much less. One ton of brown coal from Tollwitz ought, for instance, according to theory, to evaporate 18·6 cubic feet of water, whilst, in reality, only 3·8 cubic feet are evaporated by it in the salt works at Dürrenberg.

3. The Society for Promoting Industry in Prussia has determined the following results:—

| Kinds of Brown Coal. | 1 ton Prussian, or 7⅛ cubic feet weigh lbs. | Amount of Water per cent. | Amount of Ash. | | 1 lb. of Brown Coal evaporates water of 0° into steam of 110°—115° C. | |
|---|---|---|---|---|---|---|
| | | | Fresh Coal per cent. | Dried Coal per cent. | Fresh Coal. | Dried Coal. |
| Brown coal from Bohemia | 296 | 28·7 | 10·67 | 14·96 | 3·87 | 5·84 |
| Brown coal from Prussia (bituminous wood) fresh | 285 | 45·9 | 3·97 | 7·34 | 2·65 | 5·76 |
| Brown coal from Prussia stored for some time .. | 267 | 23·7 | 3·65 | 4·79 | 3·96 | 5·50 |
| Brown coal from Prussia (earthy) fresh.. .. .. .. | 286 | 47·2 | 4·81 | 9·12 | 2·45 | 5·55 |
| Brown coal from Prussia in pieces.. .. .. .. .. | 300 | 47·7 | 3·31 | 6·33 | 2·16 | 5·08 |

4. According to Strippelmann, 120 cubic feet of brown coal from the Meissner are equal in effect, on an average, to 100 cubic feet of solid mass of beech wood.

5. It has been ascertained by many years' experience at the saltworks at Schönebeck, that 108 cubic feet of fir-wood, containing 70 cubic feet compact mass, replace 96 cubic feet of brown coal from Biere; it therefore stands in the proportion of 96 : 70, or of 135·7 to 100. The brown coal from the Meissner stands in proportion to the coal of Biere as 100 : 88·4

**Brown Coal Charcoal.**—Much of the brown coal of the Continent has been converted into charcoal, with a view to its use in metallurgical works; but most kinds yield a pulverulent, friable charcoal, which, after the process of carbonisation is completed, is difficult to extinguish.* Only a few kinds of lignite and pitch coal yield charcoal useful in practice. Attempts have been made to prevent the charcoal from becoming friable, by slowly charring† the brown coal either in heaps or in furnaces, after it has been perfectly dried in the air. Mayer says that very firm charcoal is obtained by charring freshly-dug lignite, without previously exposing it to the air. Compressed brown coal‡ has also been charred, and endeavours have been made to char brown coal in retorts by means of superheated steam.‖ Brown coal charcoal has been employed in the process of fining iron.§

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* Bgwkfd., xiii., 353.

The following are a few of the results of practical experiments :¶—

| | | | | | |
|---|---|---|---|---|---|
| Lignite from | Cologne | produced | per cent | of charcoal | 36·1 |
| ,, | Ireland | ,, | ,, | ,, | 57·5 |
| ,, | Friesdorf | ,, | ,, | ,, | 48·2 |
| ,, | Stösschen | ,, | ,, | ,, | 40·6 |
| ,, | Paredel | ,, | ,, | ,, | 42·0 |
| ,, | Oberpfalz | ,, | ,, | ,, | 46·0 |

Experiments** on a small scale produced charcoal—

| | | | | |
|---|---|---|---|---|
| From | Bohemian | brown coal . . | 29·3—48·4 | per cent |
| ,, | French | ,, . . | 41—49 | ,, |
| ,, | Prussian (Rhenish) | ,, . . | 28—68 | ,, |
| ,, | Brown coal, poor in ash, on an average | . . . . . . . . . | 40—50 | ,, |

Brown (pitch) coal from the Rhön,†† when charred in heaps, yielded charcoal approaching in lustre, colour, and porosity the coke produced from mineral coal; 1 lb. of it heated

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* Lamp., Fortschr., 1839, p. 38. Stud. d. Gött. Ver., ii., 169. Tunner's Jahrb., vi., 186. Oesterr. Ztschr., 1859, No. 7.

† Erdm., J. f. pr. Ch., ii., 10.

‡ Bgwkfd., v., 300; iv., 169.

‖ Ibid., xiv., 537.

§ Ibid., xi., 377. Berggeist, 1859, No. 62. B. u. h. Ztg., 1847, p. 422.

¶ Ure's Dictionary of Arts and Mines, vol. i., 689.

** Knapp, Chem. Technologie, i., 45.

†† B. u. h. Ztg., 1857, No. 17.

73 lbs. of water from 0° up to 100° C., whilst 1 lb. of the best coke, from Zwickau, heated only 65 lbs. of water. This charcoal is well adapted for operations in forges and for heating locomotives.

Brown coal from Giessen,* in the form of bituminous wood, yields charcoal which differs very little from wood charcoal, whilst the earthy brown coal from Giessen behaves similarly to non-bituminous coal. The former may be well applied in forges, and the latter yields a great deal of slag. The yield of charcoal amounts to from 32 to 36 per cent.

## MINERAL COAL.

Mineral coal† is the term applied to that fossil coal which is older than the tertiary period, and which required a longer time for its formation‡ than brown coal.

Various views have been entertained by geologists and chemists concerning the formation of coal, of which the following is a brief summary:||—

1. Coal is universally admitted to be of vegetable origin.

2. Many refer it to some peculiar changes which have taken place in wood; others, to the formation and gradual subsidence of peat bogs (Unger); others, again, have thought that fuci supply the materials for coal beds.

3. By some it is believed that coal is found upon the spots on which trees have grown and decayed. By others, it is supposed that vast masses of vegetable matter were drifted into lakes or deltas, and were there decomposed.

4. Whether the plants grew on the soil—the under clay—upon which the coal is found, or were drifted to it, there

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* Berggeist, 1859, No. 14.

† Ure's Dictionary of Arts and Mines, vol. i., 740. Erdm., J. f. pr. Ch., xvi., 416; xx., 14. Polyt. Centr., 1849, p. 122. B. u. h. Ztg., 1857, p. 382. Stein, d. Steinkohlen Sachsens, 1857. Dingl., cxvi., 113. Bgwkfd., viii., 237; x., 424; xi., 685, 697; xii., 342. Bair, Kunst- und Gewerbeblatt: März, 1836. Dingl., xiv., 500. Bruhn Steinkohlenbüchlein, 1840. Viebahn, Statistik d. zollv. u. nördl. Deutchlands, p. 666.

‡ Polyt. Centr., 1853, p. 185. Karst., Arch., xi., 379. Dingl., cv., 460. Knapp, Chem. Techn., i., 17. Liebig's Jahresber., 1847-48, p. 1295. Bgwkfd., viii., 449. Bischoff, Phys. u. Chem. Geologie, ii., 1755.

|| Ure's Dictionary of Arts and Mines, vol. i., p. 742.

must have been long periods during which nothing but vegetable matter was deposited, and then followed a submergence of this land, and consequently vast accumulations of mud and sand.

Henry Rogers and others suppose that the whole period of the coal measures was characterised by a general slow subsidence of the coasts, on which we conceive that the vegetation of the coal grew; that this vertical depression was, however, interrupted by pauses and gradual upward movements of less frequency and duration, and that these nearly statical conditions of the land, alternated with great paroxysmal displacements of the level, caused by the mighty pulsations of earthquakes.

The difficulties consist mainly in the following facts:—

1. That there is no clear evidence that anything like *ligneous structure* can be detected in coal.

2. That the *woody matter* found in coal is never converted into coal, although it sometimes appears as if the bark were so changed.

3. That the coal always arranges itself in exact obedience to the underlying surface, as though a semi-fluid mass had been spread out on a previously formed solid bed.

4. The thinning out of true coal to extreme tenuity, as mentioned by Professor Rogers, numerous examples of which appear in this country.

5. The extreme difficulty connected with the subsidence of the surface of the earth, to such a depth as that to which the lowest seams of coal extend.

These questions are open for further examination. There can, however, be no doubt of the vegetable origin of coal; the only questions are, the conditions of change by which bituminous coal has been produced from vegetable fibre, and that we have not completed all the links in the chain between brown coal and true coal.

The following table shows, at a glance, the chemical difference between wood and brown coal, on the one hand, and anthracite on the other, and serves to show the chemical changes by which wood is supposed to pass into bituminous and, eventually, into anthracite coal:—

| | Locality | Authority. | Carbon. | Hydrogen. | Oxygen. | Nitrogen. |
|---|---|---|---|---|---|---|
| Pure woody fibre | — | Schœdler. | 52·65 | 5·25 | 42·10 | — |
| Beech | — | Chevandier | 48·89 | 6·07 | 43·11 | 0·93 |
| Oak | — | ,, | 50·64 | 6·03 | 42·05 | 1·28 |
| Peat | Holland | Milder | 59·27 | 5·41 | 35·32 | — |
| ,, | Long | Regnault | 60·06 | 6·21 | 33·73 | — |
| ,, | Bog of Allen | Kane | 61·02 | 5·77 | 32·40 | 0·80 |
| ,, | Upper Shannon | ,, | 61·21 | 5·61 | 31·44 | 1·62 |
| Lignite | Cologne | Regnault | 63·42 | 4·98 | 27·11 | — |
| ,, | Patagonia | J. A. Phillips | 62·19 | 5·08 | 19·44 | — |
| Brown coal | Lower Alps | Regnault | 69·05 | 5·20 | 22·74 | — |
| ,, | Wigan | J. A. Phillips | 80·21 | 6·30 | 8·54 | — |
| ,, | Bog Head | Hofmann | 65·66 | 8·90 | — | — |
| ,, | ,, | Anderson | 64·02 | 8·09 | 5 66 | 0·55 |
| Cannel coal | Wigan | Richardson | 83·75 | 5·66 | 8·03 | — |
| Cherry Coal | Newcastle | ,, | 81·20 | 5·04 | 8·43 | — |
| Carr's Hartley | ,, | Admiralty Inquiry | 79·83 | 5·11 | 7·26 | 1·17 |
| Steam Wallsend | ,, | ,, | 83·71 | 5·30 | 2·79 | 1·06 |
| Resolven | South Wales | ,, | 79·33 | 4·75 | — | 1·38 |
| Neath Abbey | ,, | ,, | 89·04 | 5·05 | — | 1·07 |
| Graigola | ,, | ,, | 84·87 | 3·84 | 7·19 | 0·41 |
| Aberamon | ,, | ,, | 90·94 | 4·28 | 0·94 | 1·21 |
| Anthracite | ,, | ,, | 91·44 | 3·46 | 0·79 | 0·21 |
| ,, | Slievardagh, Ireland | ,, | 80·03 | 2·30 | — | 0·23 |
| ,, | Vizille | Jacqueline | 94·09 | 1·85 | — | — |
| ,, | Swansea | Regnault | 91·29 | 2·33 | 0·82 | 0·45 |

The following general statement of the geological conditions of the coal measures of these islands is from the pen of the late Dr. Ure (vol. i., p. 750), as is also the description of the Scotch coal fields:—

"The great carboniferous formations of these islands may be subdivided into four orders of rocks:—

"1. The coal measures, including their manifold alternations of coal beds, sandstones, and shales;

"2. The millstone grist and shale, towards the bottom of the coal measures;

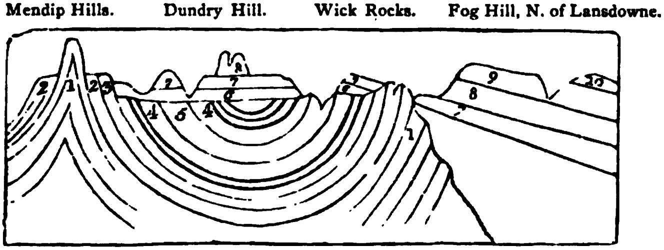
"3. The carboniferous limestone, which, projecting to considerable heights above the outcrop of the coal and grit, acquires the title of mountain limestone;

"4. The old red sandstone, or connecting link with the transition and primary rock basin in which the coal system lies.

"The coal series usually, but not invariably, consists of a regular alternation of mineral strata, deposited in a great concavity or basin, the sides and bottom of which are composed of transition rocks. This arrangement will be clearly understood by inspecting Fig. 74, which represents a section of the coal field south of Malmsbury.

"No. 1, or the old red sandstone, may, therefore, be regarded as the characteristic lining of the coal basins; but this sandstone rests on transition limestone, and this limestone on highly inclined beds of slaty micaceous sandstone, which, on the one hand, alternates with and passes into a coarse breccia, having grains as large as peas, and, on the other, into a soft argillaceous slate. The micaceous sandstone stands bare on the north-eastern border of the Forest of Dean, near the southern extremity of the chain of transition limestone which extends from Stoke Edith, near Hereford, to Flaxley on the Severn. It is traversed by a defile through which the road from Gloucester to Ross winds. The abruptness of this pass gives it a wild and mountainous character, and affords the best opportunity of examining the varieties of the rock.

FIG. 74.



1, 1, Old red sandstone. 2, Mountain limestone. 3, Millstone grit.
4, 4, Coal seams. 5, Pennant, or coarse sandstone. 6, New red sandstone, or red marl.
7, 7, Lias. 8, 8, Inferior oolite. 9, Great oolite. 10, Cornbrash, and Forest marble.

"The *limestone* consists of its *lower beds* of fine-grained, tender, extremely argillaceous state, known in the district by the name of *water-stone*, in consequence of the wet soil that is found wherever it appears at the surface. Calcareous matter is interspersed in it, but sparingly. Its *upper beds* consist of shale, alternating with extensive beds of stratified limestone. The lowest of the calcareous strata are thin, and alternate with shale. On these repose thicker strata of more compact limestone, often of dull blue colour. The beds are frequently dolomitic, which is indicated by straw yellow, or dark pink, colour, and by the sandy or glimmering aspect of the rock.

"The *old red sandstone*, whose limits are so restricted in other parts of England, here occupies an extensive area. The space which it covers, its great thickness, its high inclination, the abrupt character of the surface over which it prevails, and the consequent display of its strata in many natural sections, present, in this district, advantages for studying the formation which are not to be met with elsewhere in South Britain. In the neighbourhood of Mitchell Dean, the total thickness of this formation, interposed conformably between the transition and mountain limestone, is from 600 to 800 fathoms. The old red sandstone is characterised, in its upper portion, by the presence of siliceous conglomerate, containing siliceous pebbles, which is applied extensively to the fabrication of millstones near Monmouth, and on the banks of the Wye. This sandstone encircles the Forest with a ring of very elevated ground, whose long and lofty ridges on the eastern frontier overhang the valley of the Severn.

"The *mountain, or carboniferous limestone*, is distinguished from transition limestone rather by its position than by any very wide difference in its general character or organic remains. According to the measurements of Mr. Mushet, the total thickness of the mountain limestone in this field is about 120 fathoms. The zone of limestone belonging to this coal basin is from a furlong to a mile in breadth on the surface of the ground, according as the dip of the strata is more or less rapid. The angle of the dip on the northern and western border is often no more than 10°, but on the eastern it frequently amounts to 80°. The calcareous zone that defines the outer circle of the basin suffers only one short interruption, scarcely three miles in length, where, in consequence of a fault, the limestone disappears, and the coal measures are seen in contact with the old red sandstone.

"*Coal Measures.*—Their aggregate thickness amounts, according to Mr. Mushet, to about 500 fathoms. 1. The lowest beds, which repose on the mountain limestone, are about 40 fathoms thick, and consist here, as in the Bristol coal-basin, of a red siliceous grit, alternating with conglomerate, used for millstones, and with clay, occasionally used for ochre. 2. These beds are succeeded by a series about 120 fathoms thick, in which a grey gritstone predominates, alternating in the lower part with shale, and containing six seams of coal. The grits are of a fissile character, and are quarried extensively for flag-stone, ashlars, and fire-stone. 3. A bed of grit 25 fathoms thick, quarried for hearth-stone, separates the preceding series from the following, or the fourth, which is about 115 fathoms thick, and consists of from twelve to fourteen seams of coal, alternating with shale. 5. To this succeeds a straw-coloured sandstone, nearly 100 fathoms thick, forming a high ridge in the interior of the basin. It contains several thin seams of coal, from 6 to 16 inches in thickness. 6. On this reposes a series of about 12 fathoms thick, consisting of three seams of coal, alternating with shale. 7. This is covered with alternate beds of grit and shale, whose aggregate thickness is about 100 fathoms, occupying a tract in the centre of the basin about 4 miles long and 2 miles broad. The sandstone, No. 5, is probably the equivalent of the Pennant in the preceding figure.

"The floor, or pavement, immediately under the coal beds is, almost without exception, a greyish-slate clay, which, when made into bricks, strongly resists the fire. This fire-clay varies in thickness from a fraction of an inch to several fathoms. Clay iron-stone is often disseminated through the shale."

The above description by Dr. Ure holds perfectly correct for the great coal fields of south-western England, where we have *coal measures, millstone grit,* and *mountain limestone* in regular order, the latter being at the base of the system. As we proceed northward to Yorkshire and Northumberland, the limestone begins to alternate with the true coal measures, the two deposits forming together a series of strata about 1000 feet in thickness. To this mixed formation succeeds the great mass of genuine mountain limestone. In Fifeshire, in Scotland, we observe a still greater departure from the type of the south of England, or a more complete intercalation of dense masses of marine limestone, with sandstone and shales containing coal.

"At Brora, Sutherlandshire, we have a coal formation belonging to the lower divisions of the oolite period; and in the north-east of Yorkshire we have a similar formation.

"The Brora coal field is the most remarkable example in this, or in, perhaps, any country hitherto investigated, of a pseudo coal-basin among the deeper secondary strata, but above the new sandstone or red marl formation. The Rev. Dr. Buckland and Sir C. Lyell, after visiting it in 1824, had expressed an opinion that the strata there were wholly unconnected with the proper coal formation below the new red sandstone, and were, in fact, the equivalent of the oolitic series; an opinion fully confirmed by the subsequent researches of Sir R. Murchison (Geol. Trans. for 1827, p. 293). The Brora coal field forms a part of those secondary deposits which range along the south-east coast of Sutherland, occupying a narrow tract of about 20 miles in length, and 3 at its greatest breadth.

"One stratum of the Brora coal pit is a coal shale composed of a reed-like striated plant of the natural order *equisetum*, which seems to have contributed largely towards the formation of that variety of coal. From this coal shale the next transition upwards is into a purer bituminous substance approaching to *jet*, which constitutes the great bed of coal. This is from 3 feet 3 inches to 3 feet 8 inches thick, and is divided nearly in the middle by a thin layer of impure indurated shale charged with pyrites, which, if not carefully excluded from the mass, sometimes occasions spontaneous combustion upon exposure to the atmosphere; and so much, indeed, is that mineral disseminated throughout the district, that the shales may be generally termed "pyritiferous." Inattention on the part of the workmen, in 1817, in leaving a large quantity of this pyritic matter to accumulate in the pit, occasioned a spontaneous combustion, which was extinguished only by excluding the air; indeed the coal-pit was closed in and remained unworked for four years; the fire broke out again in the pit in 1827.

"The purer part of the Brora coal resembles common pit coal, but its powder has the red ferruginous tinge of pulverised lignites. It may be considered one of the last links between lignite and true coal, approaching very nearly in character to jet, though less tenacious than that mineral, and, when burnt, exhaling but slightly the vegetable odour so peculiar to all imperfectly bituminised substances. The fossil remains of shells and plants prove the Brora coal to be analogous to that of the eastern moorlands of Yorkshire, although the extraordinary thickness of the former, compared with any similar deposit of the latter (which never exceeds from 12 to 17 inches), might have formerly led to the belief that it was a detached and anomalous deposit of true coal, rather than a lignite of any of the formations above the new red sandstone. Such misconception might more easily arise in the infancy of geology, when the strata were not identified by their fossil organic remains.

"On the coast of Yorkshire, the strata of this pseudo coal formation appear in the following descending order, from Filey Bay to Whitby:—

"1. Coral rag. 2. Calcareous grit. 3. Shale with fossils of the Oxford clay. 4. Kelloway rock (swelling out into an important arenaceous formation). 5. Cornbrash. 6. Coaly grit of Smith. 7. Pierstone (according to Mr. Smith, the equivalent of the great oolite). 8. Sandstone and shale with peculiar plants and various seams of coal. 9. A bed with fossils of the inferior oolite. 10. Marlstone (?). 11. Alum-shale or lias. All the above strata are identified by abundant organic remains.

"In the oolitic series, therefore, where the several strata are developed in conformity with the more ordinary type of these formations, we may venture to predict with certainty that no carboniferous deposits of any great value will ever be discovered, at all events in Great Britain."

The most complete and simple form of a coal field is the entire basin-shape, which we find, in some instances, without a dislocation, whilst a great coal basin is frequently divided by dislocations into numerous subordinate coal fields.

The coal basins are generally elliptical, sometimes nearly circular, but are often very eccentric, being much greater in length than in breadth, and, in the short diameter, one side of the basin has frequently a much greater dip than the other, which circumstance throws the trough or lower part of the basin concavity much nearer to the one side than to the other. From this view of one entire basin, it is evident that the dip of the coal strata belonging to it runs in opposite directions, on the opposite sides, and that all the strata regularly crop out, and meet the alluvial cover in every point of the circumferential space, like the edges of a nest of common basins.

The absolute shape of the coal fields in Great Britain has been ascertained with surprising precision. To whatever depth a coal mine is drained of its water, from that depth it is worked up to the rise of the water-level line, and each miner continues to extend his room or working place till his seam of coal meets the alluvial cover of the outcrop, or is cut off by a dislocation of the strata. In this way the miner travels in succession over every point of his field, and can portray its basin-shape most minutely.

The following tables* show the increase and vast importance of British coal:—

*The Number of Collieries at Work, and the Production of Coal in the United Kingdom since* 1854.

| | Number of Collieries at Work. | Tons of Coal raised. |
|---|---|---|
| 1854 | 2,397 | 64,661,401 |
| 1855 | 2,613 | 64,453,079 |
| 1856 | 2,829 | 66,645,450 |
| 1857 | 2,867 | 65,394,707 |
| 1858 | 2,958 | 65,008,649 |
| 1859 | 2,948 | 71,979,763 |
| 1860 | 3,009 | 80,042,698 |
| 1861 | 3,052 | 85,635,214 |
| 1862 | 3,088 | 83,638,338 |
| 1863 | 3,160 | 88,292,215 |
| 1864 | 3,268 | 92,787,873 |
| 1865 | 3,614 | 98,150,587 |
| 1866 | 3,256 | 101,630,544 |
| 1867 | 3,188 | 104,500,480 |
| 1868 | 3,258 | — |

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* URE's Dictionary of Arts and Mines, vol. i., 764.

### *Detailed Statement of the Production of Coal in the United Kingdom.*

| | 1862.<br>tons. | 1863.<br>tons. | 1864.<br>tons. | 1865.<br>tons. |
|---|---|---|---|---|
| Northumberland<br>Durham .. .. | 19,360,356 | 22,154,146 | 23,248,367 | 25,032,694 |
| Cumberland .. .. .. | 1,330,287 | 1,327,368 | 1,380,795 | 1,431,047 |
| Yorkshire.. .. .. .. | 9.255.500 | 9,402.500 | 8,809,600 | 9,355,100 |
| Derbyshire .. .. .. | 4,534,800 | 4,550,750 | 4,470,750 | 4,595,750 |
| Nottinghamshire .. .. | 732,666 | 750,000 | 796,700 | 1,095,500 |
| Leicestershire .. .. .. | 696,024 | 805,750 | 890.500 | 965,500 |
| Warwickshire .. .. .. | 678,000 | 685,500 | 754,000 | 859,000 |
| Staffordshire<br>Worcestershire .. .. | 7,522,750 | 7,870,320 | 11,459,851 | 12,200,989 |
| Lancashire .. .. .. | 10,597,500 | 10,875.500 | 11,530,000 | 11,962,000 |
| Cheshire .. .. .. .. | 787,750 | 822,750 | 822,750 | 850,000 |
| Gloucestershire<br>Somersetshire<br>Devonshire .. .. | 1,750,000 | 1,950,000 | 1,950,000 | 1,875,000 |
| Shropshire .. .. .. | 1.029,750 | 1,150,000 | 1,150,000 | 1,135,000 |
| Monmouthshire .. .. | 3,750,000 | 4,075,000 | 4,028,500 | 4,125,000 |
| South Wales .. .. .. | 6,749,455 | 6,917,081 | 6,948,000 | 7.911,507 |
| North Wales .. .. .. | 1,660,000 | 1,728,000 | 1,987,060 | 1,983,000 |
| Scotland .. .. .. .. | 11,076,000 | 11,100,500 | 12,400,000 | 12,650,000 |
| Ireland .. .. .. .. | 127,500 | 127,050 | 125,000 | 123,500 |
| Total production of the United Kingdom .. | 81,638,338 | 86,292,215 | 92,787,873 | 98,150,587 |

### *Coal used in the Manufacture of Iron, and left for General Consumption.*

| Year. | Manufacture of Pig-Iron. | Pig-Iron Exported. | Pig-Iron left to be converted into Bar-Iron. | Total of Coal used in Iron Manufacture. * | Coal left to be consumed for all other purposes. | After Coal Consumption for Iron Manufacture, leaves for each head of the Population. | | | |
|---|---|---|---|---|---|---|---|---|---|
| | tons. | tons. | tons. | tons. | tons. | tons | cwts. | qrs. | lbs. |
| 1859 | 3,712,904 | 316,376 | 3,396,528 | 22,517,080 | 42,335,436 | 1 | 17 | 0 | 13 |
| 1860 | 3,826,752 | 342,566 | 3,484,186 | 23,152,279 | 49,449,162 | 2 | 3 | 0 | 12 |
| 1861 | 3,712,390 | 388,004 | 3,324,346 | 22,273,762 | 55,383,267 | 2 | 7 | 3 | 3 |
| 1862 | 3,943,469 | 444,454 | 3,499,015 | 23,552,107 | 51,650,879 | 2 | 4 | 0 | 13 |
| 1863 | 4,510,040 | 466,275 | 4,024,765 | 27,013,082. | 52,877,171 | 2 | 5 | 2 | 23 |
| 1864 | 4,767,951 | 465,985 | 4,301,966 | 28,715,439 | 55,137,526 | 2 | 6 | 0 | 3 |
| 1865 | 4,819,254 | 543,018 | 4,276,236 | 28,783,052 | 59,197,058 | 2 | 9 | 0 | 8 |

* This is estimated at 3 tons of coal for blast furnaces, engine fires, and all other purposes, in producing 1 ton of pig-iron, and 3 tons 7 cwts. for converting each ton of pig-iron into finished iron, every operation included.

The following summary will likewise be interesting :—

| | |
|---|---|
| Value of the coal annually raised in Great Britain (98,000,000 tons) estimated at the pit mouth . . . . . . . . . . . . . | £24,500,000 |
| Mean annual value at the place of consumption | 33,000,000 |
| Capital engaged in the coal trade. . . . . | 22,500,000 |
| Mean annual value at the furnace of pig-iron produced by British coal . . . . . . . . | 11,770,000 |

## Foreign Coal Fields.*

The period has not yet arrived when we can with any certainty state the actual number of coal basins in the world; they must, however, amount at least to from 250 to 300 principal coal fields, and many of these are subdivided by the disturbed position of the strata into subordinate basins.

The basins or coal areas may, however, be grouped into a comparatively small number of districts, many of which are little known, and entirely unmeasured. The greater number occur in Western Europe and Eastern North America, while Central and Southern Africa, South America, and a large part of Asia are almost without any trace of true carboniferous rocks.

**North America.**—There are in North America four principal coal areas, compared with which, the richest deposits of other countries are comparatively insignificant. These are the great central coal fields of the Alleghanies, the coal fields of Illinois, and the basin of the Ohio, that of the basin of the Missouri, and those of Nova Scotia, New Brunswick, and Cape Breton. There are, besides, many smaller coal areas which, in other countries, might well take rank as of vast national importance, and which, even in North America, will one day contribute greatly to the riches of the various States.

The Alleghany or Appalachian coal field measures 750 miles in length, with a mean breadth of 85 miles, and traverses eight of the principal states in the American Union. Its whole area is estimated at not less than 65,000 square miles; the coal is bituminous and used for gas.

Coal has been found in Lousiana, on the Iberville rivers, and on the shores of Lake Bistineau; it is also reported as having been found at Lake Borgne, but this is probably a lignite. In Kentucky, both bituminous and cannel coal are worked in seams about 3 or 4 feet thick, the cannel being sometimes associated with the bituminous coal as a portion of the same seam, and there are, in addition, valuable bands of iron ore (the argillaceous carbonate). The coal field of Kentucky extends over about 9000 square miles. In Western Virginia there are several coal fields of variable thickness, one being 9½ feet, two others 5, and others 3 or 4 feet. On the whole, there seem to be at least 40 feet of coal distributed in thirteen seams. In the Ohio district, the whole coal field affords, on an average, as much as 6 feet of coal. The Maryland district is less extensive, but is remarkable as containing the best and most useful coal, and is now worked to some extent at Frostbury. There appear to be about 30 feet of good coal in four seams, besides many others of less importance. The quality is intermediate between bituminous and anthracitic, and is considered well adapted for the manufacture of iron. Lastly, in Pennsylvania, there are generally from two to five beds capable of being worked, yielding, on an average, 10 feet of workable coal, and amongst them one bed, consisting of bituminous coal, is traceable for no less than 450 miles, its thickness being from 12 to 14 feet on the south-eastern border, but gradually diminishing to 5 or 6 feet. Besides the bituminous coal, there are in Pennsylvania the largest anthracite deposits in the States, occupying as much as 250,000 acres, and divided into three principal districts.

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* **Ure's Dictionary of Arts and Mines, vol. i., p. 756.**

The Illinois coal field, in the plain of the Mississippi, is only second in importance to the vast area already described. Four principal divisions of this field can be traced, of which the first, or Indian district, contains several seams of bituminous coal, distributed over an area of nearly 8000 square miles. It is of excellent quality for many purposes; one kind burning with much light and very freely, approaching cannel coal in some of its properties; other kinds consist of caking or splint coal. In addition to the Indian coal field, there appear to be as much as 48,000 square miles of coal area in other divisions of the Illinois district, although these are less known, and at present not much worked. However, 30,000 acres in the state of Illinois supply coal of excellent quality, and with great facility. The coal is generally bituminous.

The third great coal area of the United States is that of the Missouri, which is, at present, comparatively unknown, although certainly of great importance.

Taylor states that at least one-eighth of the state of Missouri, or 6000 square miles, is overlaid by coal measures. It is stated that bituminous coal has been found in the Arkansas valley, and brown coal and lignite in abundance in the Upper Missouri valley.

*Produce of Pennsylvania from* 1858 *to* 1863.

|  | Schuylkill District. Tons. | Middle District. Tons. | Wyoming District. Tons. | Total. Tons. |
|---|---|---|---|---|
| 1858. | 3,212,879. | 909,000. | 2,186,094. | 6,524,838. |
| 1859. | 3,598,531. | 1,050,659. | 2,731,236. | 7,517,516. |
| 1860. | 3,815,822. | 1,091,032. | 2,856,896. | 8,059,017. |
| 1861. | 3,114,254. | 994,705. | 2,918,458. | 7,487,672. |
| 1862. | 3,549,844. | 396,227. | 3,130,887. | 7,640,905. |
| 1863. | 4,151,882. | 609,558. | 3,760,374. | 9,420,135. |

*Coal Product of the Loyal United States, year ending June,* 1864, *from the Returns made to the Inland Revenue Department.*

|  | Tons. |
|---|---|
| Rhode Island | 3,656 |
| Pennsylvania | 12,698,412 |
| Maryland | 787,269 |
| District Columbia | 742 |
| Western Virginia | 398,815 |
| Kentucky | 91,036 |
| Missouri | 66,187 |
| Ohio | 1,324,685 |
| Indiana | 146,787 |
| Illinois | 925,293 |
| Michigan | 16,296 |
| Minnesota | 50,204 |
| Kansas | 236 |
| California | 44,938 |
| Washington Territory | 7,754 |
|  | 16,472,410 |

The anthracite coal fields of Pennsylvania are divided into three great districts, viz., 1, Southern or Schuylkill district, embracing the Lehigh and Lyken's valley coal; 2, the Middle district, embracing the Beaver Meadow, Shamokin, and Trevorton coal; the 3rd, Northern, or Wyoming, and

Lackawama, embracing the Scranton, Pittston, and Lackawama coals.

*Total Produce of Pennsylvania in* 1864.

| | Tons. |
|---|---|
| Anthracite districts . . . . . . | 9,876,174 |
| Broad top or semi-anthracite . . | 422,992 |
| Bituminous districts . . . . . . | 2,399,246 |
| | 12,698,412 |

**British America** contains coal in the Provinces of New Brunswick and Nova Scotia. In the former there are three coal fields, occupying, in all, no less than 8000 square miles; in the latter coal abounds in several very distinct localities. It is generally found in thin seams, lying horizontally, and is almost entirely bituminous.

**Nova Scotia** possesses three coal regions, of which the Northern presents a total thickness of no less than 14,570 feet of measures, having seventy seams, whose aggregate magnitude is only 44 feet, the thickest bed being less than 4 feet. The Pictou, or central, district has a thickness of 7590 feet of strata, but the coal is far more abundant, one seam measuring nearly 30 feet; part of the coal is of excellent quality, and adapted for steam purposes. The southern area is of less importance. Besides the Nova Scotia coal fields, there are three others at Cape Breton, yielding different kinds of coal, of which one, the Sydney coal, is admirably adapted for domestic purposes. There are here fourteen seams above 3 feet thick, one being 11 and one 9 feet.

**Newfoundland Coal Field.**—This field is estimated at about 5000 square miles. According to Mr. Jukes, now Director of the Geological Survey in Ireland, the entire western side of the island, along a space of 356 miles in breadth, is occupied by secondary and carboniferous rocks. The coal on the south-western point of the island has been traced, at intervals, along a space of 150 to 200 miles, to the north-east.

**Greenland.**—Captain Scoresby discovered a regular coal formation here. At Hasen Island and also at Disco Island, on the western coast, brown coal has been found.

**Arctic Ocean.**—At Byam, Martin's Island, a coal formation exists, and at Melville Island several varieties of coal have been discovered, much of it being of an anthracitic or semi-anthracitic character. We learn that at Prince Regent's Inlet indications of coal have been observed.

**Russian America.**—Beyond the Ice Cape, and at Point Barrow, coal was observed on the beach, and it has been found at Point Franklin by digging but a few feet below the surface.

**Oregon Territory.**—Coal has been discovered and worked in Wallamette Valley, nearly 100 miles above Oregon city, and anthracite has been observed by Sir George Simpson about 30 miles up one of the tributaries of the Columbia river.

**United States of Columbia.**—Immense deposits of cannel coal have been discovered in the province of Rio Hacha.

**Mexico.**—On Salado river, coal is worked by an American company. A coal formation, 50 miles in breadth, crosses the Rio Grande, from Texas into Mexico, at Loredo, and on the Mexican shore, within 200 yards of the Rio Grande, a remarkably fine vein of coal, 8 feet thick, occurs.

**Texas.**—Coal is known to exist in Texas, though the country has not been geologically examined. The Trinity Coal and Mining Company was incorporated by the Texan Congress in 1840, and worked both anthracite and a semi-bituminous coal. Kennedy in his work "Texas, its Geography, &c.," says, coal, both anthracite and bituminous, abounds from the Trinity River to the Rio Grande.

**South America.**—In the Republic of New Granada, especially at Santa Fé de Bogota, coal occurs, also in the island of Santa Clara, and brown coal in the Province of Panama.

**Venezuela** is said to contain coal, but whether brown or bituminous coal does not appear certain.

**Peru** apparently possesses some coal.

**Chili.**—The coal of this district has been examined by many American engineers, also by Captains Fitzroy and Beechy, and Mr. Darwin. In 1844, upwards of twenty coal mines were open in the neighbourhood of Conception. At Tulcahnano, a new seam of 4½ feet was proved. The coal is described by W. R. Johnson as "in external appearance nearly related to many of the richest bituminous coals of America and Europe," and Mr. Wheelwright, in his report on the mines and coals of Chili, says—"In fact the whole southern country is nothing but a mine of coal."

**Brazil** does not possess much coal of any value; there are a few lignites.

**The West-Indian Islands.**—Cuba, in the vicinity of Havannah, produces a kind of asphaltum much resembling coal, the analysis of which gives—Carbon, 34·97; volatile matter, 63·00; ashes, 2·03. At New Havannah, a similar combustible is found, but it contains 71·84 of carbon. True coal does not appear to have been found in Jamaica. Sir H. de la Beche (Trans. Geological Society of London), describes three or four thin seams of coal, imbedded in shale, near the north-eastern extremity of the island.

**Barbadoes.**—Bitumen is found plentifully, and, on Grove Plantation estate, a good coal is said to be produced.

**Trinidad.**—The pitch lake of this island is well known. Near it, and, it is believed, extending under it, a true coal of superior quality is worked.

**India.**—The following information is extracted from the "Memoirs of the Geological Survey of India":—

*Production of Coal in India.*

| Districts. | 1858. | 1859. | 1860. |
|---|---|---|---|
| Runnigang coal field | 5,917,000 | 8,949,600 | 8,559,097 |
| Rajmahal Hills | 219,000 | 843,000 | 1,222,860 |
| Kurhrbari | 4,000 | 108,182 | 275,256 |
| Palamow | — | 28,648 | 30,900 |
| Syhlet Hills | 22,319 | 32,498 | — |
| Total, in mannels | 6,162,319 | 9,961,928 | 10,088,113 |
| Or in tons | 226,140 | 365,575 | 370,206 |

Of the Singrowli coal field, which lies to the south of the river Sone, in the Rewah territory, Dr. Oldham states that he has not been able to procure any return, but he is, however, aware that the amount of coal raised has been small, and will not affect the general total. More than one bed of coal has been practically examined in the continuation of this coal field to the west, and towards Singapore; but none of these are as yet at work as collieries. The Nerbudda Valley has long been known to contain coal, but, owing to the distance from any available market, and the comparative inaccessibility of the localities where it occurs, it has not hitherto been economised.

In other parts of the North-Western Provinces there is no known workable coal. Seams of lignite, of very irregular size and very limited extent, occur in several places along the foot of the sub-Himalayas, marking a certain group of sandstone rocks of comparatively recent date, but nowhere are these deposits known to be of sufficient extent to render it probable that they will ever be of any practical use.

In Oude, no coal is known to occur, nor in the Punjaub, if we except the patches of lignite which have been found, as in the North-Western Provinces, in several localities along the base of the outer Himalaya, as well as in the Salt Range.

In Scinde, the only coal raised was that of Synah Valley, as given above, but the irregularity and the small extent of this deposit has caused it to be abandoned. It was, in fact, an irregular patch of lignite.

In Bombay and Hyderabad, no coal is known to occur. In Nagpore, a small coal field exists near to Merut, on the border of the Nerbudda district, which may, in fact, be considered a continuation (although actually separated) of the Nerbudda deposits; the coal is not now utilised.

In Madras, no coal is known. It has been more than once, and even very recently, stated that coal occurs on the Godavery or some of its tributaries, but as yet nothing but black shales, which will not support combustion, and which are, in all probability, of a totally different age from the coal-bearing rocks of India, have been met with.

**New South Wales.**—Running down the rivers Bremer and Brisbane to the town of Brisbane, numerous outcrops of coal may be seen in the banks. Several works are situated about half-way between Ipswich and Brisbane. In the parish of Maggil several collieries are established. "The coal varies from 5 to 6 feet in thickness, dipping south forty degrees east, angle from seven to eight degrees, although not worked to its whole thickness, except where they wanted head room for the 'horse way.' The main coal separates from the top coal at about 4 feet; the 2 feet of the top coal is good, but mixed with a small quantity of earth."—(*Stuchbury*). This geological surveyor has given in his report several sections of the coal on either side of the Bremer river.

The number of coal mines, their produce and value, being—

| | | | | | | |
|---|---|---|---|---|---|---|
| In 1861, 18 | mines | produced | 342,068 | tons, | valued at | £218,821 |
| ,, 1862, 33 | ,, | ,, | 476,522 | ,, | ,, | 305,235 |
| ,, 1863, 20 | ,, | ,, | 433,889 | ,, | ,, | 236,231 |

**Queensland.**—The produce of the collieries were—

| | Tons. |
|---|---|
| In 1861 . . . . . . . . . . . | 14,212 |
| ,, 1862 . . . . . . . . . . . | 24,067 |
| ,, 1863 . . . . . . . . . . . | 2,400 |

**Japan.**—In Japan, coal fields are worked in the districts of Kiusin and Nippon.

**Borneo.**—In the Province of Labuan, on the north-west coast, there is abundance of coal of good quality. The seam is generally 9 feet in thickness. The coal found here burns fast, and emits a bright flame; it soon acquires a red heat, and continues in this state until it smoulders into a white ash like that of wood; there is not much smoke from it. For several years past, the coal mines of Moara have ceased to be worked.

**China.**—There appears to be much good coal in China. It is procured from a mine on the River Yang-tse-Kiang about 400 miles from its mouth. Of the other coal-producing districts little is known.

Mr. Consul Morgan's report for 1864 on the trade of Tien-tsin says:—"I allude to coal, extensive mines of which exist in the mountains to the north and west of Pekin. It costs about 16s. per ton at the pit's mouth, and more than double this amount per ton is paid for transport to the coast, but the mines are worked in the rudest way, and the little coal which finds its way from the western range of Tien-tsin is conveyed on mules or camels from the mountains of Tang-chow on the Peiho, and thence down the river in boats to this port. From the mines in the northern range there is water communication of an indifferent kind to Tien-tsin, but the quality of their coal is much inferior to that which comes from the western mountains."

**Europe.**—The principal coal fields of the Continent of Europe are those of Belgium, France, Spain (in the Asturias), Germany, and Russia (on the Donetz).

**Belgium.**—The Belgian coal field is of great importance, and occupies two districts—that of Liege, and that of Hainault, the former containing 100,000, and the latter 200,000, acres. In each, the number of coal seams is very considerable, but the beds are thin and so much disturbed as to require special modes of working. The quality of coal is very various, including one peculiar kind, the Flenu coal, unlike any found in Great Britain, except at Swansea. It burns rapidly, with much flame and smoke, not giving out an intense heat, and having a somewhat disagreeable smell. There are nearly fifty seams of this coal in the Mons district. No iron has been found with the Belgian coal.

Mr. Dunn, Her Majesty's Inspector of Collieries, has reported on the coal of Belgium, and, first quoting a report which announces that the mines would be exhausted in twenty years, says:—"This announcement comes with appalling force upon the numerous joint-stock companies. According to the report of M. Briavionne, Belgium is traversing towards a momentous crisis, and I am much inclined to confirm the writer's opinion that, according to the present plan of carrying on the collieries, notwithstanding the high price received for the coals, yet that coal will not be found workable to profit below the depth of 250 or 260 fathoms, inasmuch as the deeper they go, the more destructive and unmanageable will be the effects of the pressure."—*The Government Mining Engineer's Report.*

Belgium is traversed in a direction from nearly west-south-west to east-north-east by a large zone of bituminous coal formation. The entire region is generally described under two principal divisions.

1. The Western or Hainault division, comprising—

*a*. The two basins known as Levant and Couchant of Mons; that of Charleroi.

*b*. The basin of Namur.

2. The Eastern or Liège division.

**Netherlands.**—There is only one coal mine in Holland. It is situated in the Province of Limburg.

**France.**—The most important, largest, and best known coal fields of France are those of the basin of the Loire and of St. Etienne, comprising about 50,000 acres. In this basin are eighteen beds of bituminous coal, and, in the immediate neighbourhood, several smaller basins containing anthracite. There are other valuable deposits in Alsace, several in Burgundy worked by very deep pits, and of considerable extent; some in Auvergne, with coal of various qualities; some in Languedoc and Provence, with good coal; others at Arveyron and Limosin, and some in Normandy. Besides these, there are several others of smaller dimensions and less extent, whose resources have not yet been developed. The total area of coal in France has not been ascertained, but it probably is not less than 2000 square miles. The annual production in 1865 exceeded 11,000,000 tons. The coal of France is, however, of an inferior description, and, therefore, when a better and stronger fuel is required, the supply is obtained from foreign coal fields. The mineral combustibles of France were estimated, in 1864, by the Government engineers as follows:—

| | Tons. |
|---|---|
| Anthracites | 800,000 |
| Hard coal, short-flame | 1,400,000 |
| Forging coal | 600,000 |
| Bituminous coal, long flame | 4,000,000 |
| Soft coal, long flame | 3,000,000 |
| Lignites | 200,000 |
| | 10,000,000 |

**Spain.**—Spain contains a large quantity of coal, both bituminous and anthracite. The richest beds are in Asturias, and the measures are so broken and altered, as to be worked by almost vertical shafts through the beds themselves. In one place, upwards of eleven distinct seams have been worked, the thickest of which are nearly 14 feet. The exact area is not known, but it has been estimated by a French engineer that about 12,000,000 tons might be readily extracted from one property, without touching the portion existing at great depths. In several parts of the province the coal is now worked, and the measures seem to resemble those of the coal districts generally. The whole coal area is said to be the largest in Europe, presenting upwards of 100 workable seams, varying from 3 to 12 feet in thickness.

The Asturias Mining Company are working many mines in this region, which are said to produce 400,000 tons annually, or at least to be capable of doing so. In Catalonia and in the Basque provinces of Biscay, anthracite and bituminous coal are found.

Coal also exists in the Balearic islands.

**Portugal.**—Beds of lignite and some anthracite are known to exist, but the production of both is small.

**Italy.**—The principal coal mines are in Savoy and near Genoa. In the Appennines some coal is found; in the valley of the Po there are large deposits of good lignite, and a small quantity of good coal is worked in Sardinia.

**Germany.**—The German States embrace the following principal coal beds:—

| | |
|---|---|
| Prussian States. | Westphalia.<br>Silesia.<br>Saarbrück, and Provinces of the Bas Rhine.<br>Hesse and Hanover. |
| Other German States. | Saxony.<br>Bavaria. |

The true coal of Prussian Silesia stretches for a distance of seventeen leagues. The coal fields of Westphalia were described by Sedgwick and Murchison, in 1840. The productive coal beds are on the right bank of the Rhine, and possess many features in common with the English coal fields. Bituminous wood and lignite or brown coal occur extensively in some districts. The coal basin of Saarbrück has thus been described by Humboldt, chiefly from a communication received by M. von Dechen :—

"The depth of the coal measures at Mont St. Gilles, Liège, I have estimated at 3650 feet below the surface, and 3250 feet below the sea level. The coal basin at Mons lies fully 1750 feet deeper. These depressions, however, are trifling when compared with that of the coal strata of the Saar rivers (Saarbrück). After repeated trials I have found that the lowest coal strata known in the county of Duttweiler, near Bettingen, north-eastward from Saar-louis, dip 19,406 feet, and 20,656 below the level of the sea."

Coal is found in Würtemberg, but it is not much worked. In Saxony, extensive mines of bituminous coal exist; at Schonfield, near Zwickau, the coal alternates with porphyry. Near Dresden, a bituminous coal is also worked, and the coke manufactured from it is used in the metallurgical works at Freiberg.

Electoral Hesse produces little beyond lignite. In Hesse Cassel, some bituminous coal is worked; real stone coal is as yet only produced in the county of Schaumburg. From the Thüringerwald, some coal is obtained.

There are, at present, only three coal mines in the Grand Duchy of Baden: one at Berghaupten, in the district of Gengenbach, another at Zunsweiler, in the district of Offenburg, and a third at Duisburg, in the same district.

The most considerable quantity of Hanoverian coal is found some miles south of the capital, in the mountains called Deister and Osterwald, also at the Süntel, and in the neighbourhood of Osnabrück.

Coal and brown coal are produced in Bavaria, from Amberg, Bodenmais, Bodenwöhr, Kissingen, Munich, Southofen, Steben, Wundsiedel, Fichtelberg, and Rhein Palatinate.

The production of mineral and brown coal, in Prussia (excluding the provinces of Hanover and Hesse) amounted, in 1860, to about 276,200,000 Prussian cwts.; that of Saxony, in 1859, to 30,389,477 cwts.; and that of Bavaria, in 1860, to 5,181,636 Prussian cwts.

**Poland.**—There are several coal mines in Poland. Those of the brown produce about 1,000,000 sacks of 3½ bushels, and those of the western district 8,000,000 lbs. per annum.

**Hungary** and other countries in the east of Europe contain true coal measures of the carboniferous period, but the resources of these districts are not, at present, developed. On the banks of the Donetz in Russia, coal is worked to some extent, and is of excellent quality.

**Austria.**—Coal occurs in Styria, Carinthia, Dalmatia, the Tyrol, Moravia, Lombardy, and Venice; but 700,000 tons appear to be the maximum annual production of the empire. The basin of Vienna, in Lower Austria, produces several varieties of coal, which belong to the brown coal of the tertiary period.

**Bohemia.**—In this kingdom coals are abundant; one coal field occupies a length of 15 leagues, and a breadth of from four to five leagues. Between 300,000 and 400,000 tons are produced annually.

**Sweden.**—Anthracite is found in small quantities at Dannemora, and bituminous coal is worked at Helsingborg, at the entrance of the Baltic.

**Denmark.**—The island of Bornholm, and some other islands belonging to Denmark, produce coal, but it appears to belong to the Bovey coal variety.

**Russia.**—The Donetz coal field is the most important. In that extensive district, according to Sir R. I. Murchison, many good seams of both bituminous and anthracitic coal exist.

**Turkey.**—Coal is found bordering on the Carpathian Mountains, also in Servia, Roumelia, and Bulgaria.

The coal of Heraclia, on the south coast of the Black Sea in Anatolia, has, since the Crimean war, been exciting much attention.

**Smyrna.**—Moderately good coal is found at Nazli, near Olidin. There are other coal mines of very inferior quality.

**Greece.**—No coal, properly so called, is known to exist in Greece, but lignite has been found in several places.

The relative importance of mineral fuel in various countries, as indicated by the actual coal area and the real production of the coal fields, may be understood by a reference to the subjoined table.* These areas are based upon the data given by Mr. Taylor, but with some modifications:—

| Countries. | Coal Area in Square Miles. | Proportion of the whole Area of the Country. | Annual Production in Tons in 1865. |
|---|---|---|---|
| British Islands . . . . | 12,800 | 1—10 | 98,150,587 |
| France. . . . . . . . | 2,000 | 1—100 | 11,300,000 |
| Belgium . . . . . . . | 520 | 1—22 | 9,758,200 |
| Spain . . . . . . . . | 4,000 | 1—52 | 500,000 |
| Prussia. . . . . . . . | 1,200 | 1—90 | 10,748,685 |
| Bohemia . . . . . . . | 1,000 | 1—20 | 1,966,000 |
| United States of America | 113,000 | 2—9 | 16,472,410 |
| British North America . | 18,000 | 1—20 | 2,750,000 |

## CLASSIFICATION OF COAL.

Some mineralogists, as Dana, divide coal into bituminous and non-bituminous, and under these divisions they group the numerous sorts of coal which occur, as

### Bituminous Varieties.

1. **Pitch or Caking Coal** (Dana) which burns readily with a yellow flame, and, on being heated, unites into a solid mass, which requires to be stirred to prevent its too complete consolidation.

2. **Cherry Coal** somewhat resembles caking coal, but it burns more rapidly, with a clear yellow flame, and in burning it does not soften or cake.

3. **Splint or Splent Coal** is a term used in Scotland for a hard laminated variety of bituminous coal, intermediate in texture between caking and cannel coal. The name is derived from its splitting (or *splenting*) up in large flaggy or board-like laminæ (Page). It is a coarse kind of cannel coal (Dana). A variety of bituminous (cannel) coal, with a slaty structure, and of a harder and tougher nature than cherry coal. Splint coal is used by Lyell as the equivalent of anthracite.

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* Ure's Dictionary of Arts and Mines, vol. i., p. 744.

4. **Cannel Coal.**—A coal with a fine compact texture, and a large conchoidal fracture; it receives a good polish, and is sonorous when struck. It is coal more perfectly bituminised than No. 1. In Scotland, this coal is called *parrot coal*, from the crackling, chattering noise which it makes when first thrown into the fire.

**Jet** resembles cannel coal, but is blacker and has a far more brilliant lustre.

**Flint Coal.**—A kind of coal resembling anthracite in appearance, but containing bitumen.

**Flew Coal** resembles flint coal. It must be regarded as a local name for the coal found at Wedgebury, in Staffordshire.

**Crow Coal.**—A coal found near Alston, containing but a small quantity of bitumen.

**Albert Coal** or **Albertite.**—A bituminous coal found in Nova Scotia; it has the appearance of asphaltum, and is partly soluble (about 20 per cent), but it has not the fusibility of asphaltum.

### Non-Bituminous Varieties.

**Anthracite.**—A coal with a sharp-edged, shining, conchoidal fracture, not easily ignited, but when burning it gives out an intense heat, unaccompanied by smoke, and produces but little flame. Often called *stone coal.*

**Culm.**—An impure shaly kind of coal, or anthracite shale, as the culmniferous or anthracite shales of Devon. The term is used in parliamentary returns to signify anthracite.

**Fossil Coal.**—An American variety, more compact than artificial coke, supposed to be produced by the action of trap rock on anthracite.

**Recent Coal.**—The true coal era is a well defined one. Geologically, it lies between the old and new red sandstone rocks. A newer coal is found in the lias at Richmond in Virginia, United States, as belonging to the oolites, and at Brora in Sutherlandshire, Scotland. The coal occurring in Hanover, belongs also to the newer formation. These more recent coals are very insignificant compared with the true, old coals.

Technologically,* coal is classified according to age, on which their composition and behaviour in the fire depends.

1. **Anthracite.**†—This kind of coal shows scarcely any vegetable structure, is very brittle, of iron-black colour and metallic lustre. It is considered to be the oldest coal, and is formed by external influences upon the other kinds of mineral coal.

De la Beche describes anthracite as a variety of coal containing a larger amount of carbon and less bituminous matter than common coal.

Concerning the occurrence of anthracite, the "Memoirs of the Geological Survey" contain the following account:—"We see the same series of coal beds becoming so altered in their horizontal range that a set of beds, *bituminous* in one locality, is observed gradually to change into *anthracitic* in another. Taking the coal measures of South Wales and Monmouthshire, we have a series of accumulations in which the coal beds become not only more anthracitic towards the west, but also exhibit this change in a plane which may be considered as dipping S.S.E. at a moderate angle, the amount of which is not yet clearly ascertained; so that in the natural sections afforded, we have bituminous coal in the high grounds, and anthracitic coal beneath. This fact is readily observed either in the Neath or Swansea valleys, where we have bituminous coal on the south and anthracite on the north, and more bituminous coal beds on the heights than beneath, some distance up these valleys—those of the Nedd and Tawe. Though the terms bituminous coal and anthracite have been applied to marked differences, the changes are so gradual that there is no sudden modification to be seen. To some of the intermediate kinds the term "free burning" has been given, and thus three chief differences have been recognised."

J. P. Lesley states that anthracite is not an original variety of coal, but a modification of the same beds which remain bituminous in other parts of the region. Anthracite beds, therefore, are not separate deposits in another sea, nor coal measures in another area, nor interpolations among bituminous coal, but the bituminous beds themselves altered into a natural coke, from which the volatile bituminous oils and gases have been driven off.

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* Erdm., J. f. pr. Chem., xii., 106.

† Ure's Dictionary of Arts and Mines, vol. i., p. 173.

The term *culm* is applied both to an inferior kind of anthracite only worked for making lime, or for mixing with clay, and to the small pieces of good anthracite obtained in working the true anthracitic beds. It is also called *blind coal*, *glance coal*, and *Kilkenny coal.*

There are three very distinct "trades" in anthracite. First, that in which the coal is sold exactly as it is worked, "through and through," as it is termed, or *through culm*, which is used entirely for lime-burning. This coal is not of so pure a kind as that from which the large coal is picked out, and is sometimes called "bastard stone coal." The trade of the Neath district is entirely in this kind. In Swansea and Llanelly it is partly of this kind, and partly of that where the large coal is picked out and sold as *stone coal* for the various purposes to which that fuel is applied, leaving the small to be shipped, also for lime-burning purposes, under the name of *stone coal culm.* In Pembrokeshire, no "through culm" is shipped. There is one curious lot of 4,000 tons annually shipped in Swansea under the name of *lambskin*, which is almost dust. It is sent to one market—Cardiganshire—where it is used entirely for mixing with clay; the mixture, under the name of *fire-balls*, being applied to household purposes. This mixture, made of the ordinary *stone coal culm*, is also very commonly used in parts of Pembrokeshire and Caermarthenshire.

Anthracite coal is obtained in this country at Bideford in Devonshire, at Walsall in Staffordshire, in the western divisions of the South Wales coal field, in Ireland, and near Edinburgh. It is found abundantly in America. Professor H. D. Rogers, "Transactions of American Geologists," states that, in the great Apalachian coal fields, extending 720 miles, with a chief breadth of 180 miles, the coal is bituminous towards its western limit, where it is level and unbroken, becoming anthracitic towards the south-west, where it is disturbed. Anthracitic coal is also found in the coal fields of

France, especially in the departments of Isère, the High Alps, Gard, Mayenne, and Sarth, about 42,271,000 kilogrammes are produced annually; it is also procured from Belgium and Hanover.

Anthracite, now exclusively used for the manufacture of iron,[*] for steam engines, and domestic purposes in the United States, was some fifty years since regarded as incombustible refuse, and thrown away.

Owing to its purity, anthracite yields iron of better quality than mineral coal or coke. It is also used for the production of combustible gases,[†] and is applied in copper smelting works.[‡]

In this country, anthracite coal is used in the manufacture of iron in the following furnaces:—

| | Furnaces in Blast in 1864. |
|---|---|
| Ystalyfera in Glamorganshire . . . . . | 6 |
| Yniscedwyn in Brecknockshire . . . . | 1 |
| Brynamman in Carmarthenshire . . . | 1 |
| Kilgetty in Pembrokeshire . . . . . . | 1 |

The quantity of anthracite iron made in 1864 was 26,565 tons.

The anthracite coal worked in South Wales in 1864 amounted to 509,475 tons, viz.:—

| | Tons. |
|---|---|
| Pembrokeshire . . . . . . . . . . | 146,000 |
| Carmarthenshire and Glamorganshire . | 363,475 |

Professor W. R. Johnson, of Pennsylvania College, informs us that fourteen furnaces, using anthracite for the production of iron, were in use in the United States (1856).

Overmann[||] states that the number of blast furnaces in the United States may be estimated at 800, of which about 60 are anthracite furnaces, 8 bituminous coal furnaces, and a similar number coke furnaces; in the others, charcoal is used.

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[*] Erdm., Journ. f. pr. Chem., iv., 393; xxii., 27; xxvi., 255. Bgwkfd., i., 295, 485; ii., 397; iii., 169; iv., 175; vi., 186; vii., 126; viii., 4, 460; xiii., 39. B. u. h. Ztg., 1843, pp. 85, 964; 1849, p. 314; 1852, p. 755; 1853, p. 905; 1854, p. 149. Lamp., Fortschr., 1839, p. 36. Polyt. Centr., 1849, p. 362. Jahrb. d. k. k. geol. Reichsanst., 1852, No. 3, p. 7. Karst., Arch., 2 R., Bd. 25, pp. 579, 601.

[†] Polyt. Centr., 1846, p. 492. Bgwkfd., viii., 505. B. u. h. Ztg., 1849, p. 242.

[‡] B. u. h. Ztg., 1852, p. 326; 1859, p. 310.

[||] Overmann's Treatise on Metallurgy: New York, 1865, p. 536.

The following table shows the increase of production of anthracite in America from 1840 to 1862 inclusive, from Schuylkill, Lehigh, and Wyoming:—

| Year. | Tons. |
|---|---|
| 1840 | 864,384 |
| 1841 | 950,973 |
| 1842 | 1,108,418 |
| 1843 | 1,263,598 |
| 1844 | 1,630,850 |
| 1845 | 2,013,013 |
| 1846 | 2,344,005 |
| 1847 | 2,882,300 |
| 1848 | 3,089,238 |
| 1849 | 3,217,641 |
| 1850 | 3,321,136 |
| 1851 | 4,329,530 |
| 1852 | 4,899,975 |
| 1853 | 5,097,144 |
| 1854 | 5,831,834 |
| 1855 | 6,486,097 |
| 1856 | 6,751,542 |
| 1857 | 6,431,379 |
| 1858 | 6,819,881 |
| 1859 | 7,838,439 |
| 1860 | 8,500,550 |
| 1861 | 7,424,530 |
| 1862 | 7,527,356 |

The progress of the annual consumption of anthracite in the United States was estimated as follows:—

| | | Tons. |
|---|---|---|
| 1820 | about | 330 |
| 1825 | ,, | 35,000 |
| 1830 | ,, | 176,000 |
| 1835 | ,, | 561,000 |
| 1840 | ,, | 865,000 |
| 1845 | ,, | 2,023,000 |
| 1850 | ,, | 3,357,000 |
| 1853 | ,, | 5,195,000 |

The following statements concerning anthracite are made by Overmann*:—

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* OVERMANN'S Treatise on Metallurgy: New York, 1865, pp. 390, 535.

Anthracite is the most important and best fuel for the smelting of metals, partly because it is nearly as pure as charcoal, and generally cheaper than either that substance or coke. When a ton of bituminous coal can be bought at 50 cents, which is an average price in the coal regions of the West, a ton of coke will cost not less than two dollars, at which price many of the iron furnaces buy anthracite. The points in which the advantages of anthracite are greatest, are these:—If coal, coke, and anthracite must be transported, the latter is far before the first in cheapness. A ton of charcoal cannot be furnished, under the most advantageous circumstances, for less than six dollars. When we consider that anthracite occasions no expense in the erection of char ovens and yards, or for the superintendence of the charring operation, no interest on capital invested in a stack of wood, charcoal, or coke, there is little doubt as to the advantage, in point of cheapness, which anthracite possesses over charcoal and coke in melting.

Anthracite is not so inflammable as either dry wood or bituminous coal, but it may be made to burn quite as vividly as either, by exposing it to a strong draught, or, in a large mass, to the action of air. Since there is little or no hydrogen in this coal, it burns without flame, the absence of which arises chiefly from the lack of solid heated particles in the gases, and as transparent hot gas does not radiate heat, no matter what may be its temperature, it has been found that the anthracite flame does not heat the hearth of a reverberatory furnace so well, or so quickly, as bituminous coal or flaming wood. This evil can be remedied by applying a blast under the grate of a furnace. Fine particles of coal are thus carried over by the hot gases, and the flame so formed radiates heat as well as that of any other fuel. It is manifest that the pressure of blast, or the force of the current of air, which is to detach these particles, must be in proportion to the refractory nature of the coal. If the draught is too strong, the particles will be too large, and will, therefore, be deposited on the hearth, where the current has not sufficient strength to keep them suspended, and their effect will thus be lost. If the particles are extremely small, and the furnaces so constructed as to retain a lively current, their subsidence is prevented. A low roof is, therefore, required in burning anthracite coal in a reverberatory furnace. Another consideration which exerts an essential influence on the formation of flame, is the size of the grate. Small grates generally furnish more flame than large ones, but only when flaming fuel is used, in which the carburetted hydrogen affords the carbon as minutely as is requisite. A large grate is, in this instance, more suitable to form a good substantial flame than a small one, for a gentle draught in it will produce only small particles, while a strong blast tears off large ones, which are of little use. The truth of this explanation of the formation of flame, is forcibly illustrated in the re-heating and puddling furnaces in the iron works. For re-heating or welding iron, anthracite is decidedly preferable to bituminous coal, because it is more economical and works faster. The low roof in the re-heating furnaces is the only cause of good work with anthracite. The same coal, with the same blast and size of grate, will produce a perfectly white flame in a re-heating furnace, but we cannot obtain a similar flame from it in a puddling furnace.

The ashes which are formed by anthracite and deposited in the flues, or on the hearth, are sometimes a cause of objection. The evil, if it cannot be entirely obviated, can at least be greatly modified, by increasing the surface of the grate. It is in connection with the deposits of these ashes that the strong draught, as we remarked before, tears loose large particles of carbon which can neither be supported by the slowly moving gases, nor consumed, because their mass is too large and refractory.

Regnault and Jacquelin analysed ten kinds of anthracite, and found them to contain:—

| | | |
|---|---|---|
| Carbon . . . . . | 92—98 | per cent |
| Hydrogen . . . . | 1·25—4·28 | ,, |
| Oxygen . . . . . | 0—4·18 | ,, |
| Nitrogen. . . . . | 0·29—2·90 | ,, |

*Principal Localities of Anthracite and Anthracitic Coal, &c.*

| | Specific Gravity. | Weight of a Cubic Yard in lbs. |
|---|---|---|
| *Europe.* | | |
| South Wales:—Swansea | 1·263 | 2131 |
| Cyfarthfa | 1·337 | 2256 |
| Yniscedwin | 1·354 | 2284 |
| Average | 1·445 | 2278 |
| Ireland, mean | 1·445 | 2376 |
| France:—Allier | 1·380 | 2207 |
| Tantal | 1·390 | 2283 |
| Brassac | 1·430 | 2413 |
| Belgium:—Mons | 1·307 | 2105 |
| Westphalia | 1·305 | 2278 |
| Prussian Saxony | 1·466 | 2474 |
| Saxony | 1·300 | 2193 |
| Average of Europe | — | 2281 |
| *America.* | | |
| Pennsylvania:—Lykens Valley | 1·327 | 2240 |
| Lebanon Co., grey vein | 1·379 | 2327 |
| Schuylkill Co., Lorberry Creek | 1·472 | 2484 |
| Pottsville, Sharp Mountain | 1·412 | 2382 |
| ,, Peach | 1·446 | 2440 |
| ,, Salem Vein | 1·574 | 2649 |
| Tamaqua North Vein | 1·600 | 2700 |
| Maunch Chunk | 1·550 | 2615 |
| Nesquehoning | 1·558 | 2646 |
| Wilkesbarre, best | 1·472 | 2884 |
| West Mahoney | 1·371 | 2313 |
| Beaver Meadow | 1·600 | 2700 |
| Girardville | 1·600 | 2700 |
| Hazelton | 1·550 | 2615 |
| Broad Mountain | 1·700 | 2869 |
| Lackawanna | 1·609 | 2715 |
| Massachusetts:—Mansfield | 1·710 | 2882 |
| Rhode Island:—Portsmouth | 1·810 | 3054 |
| Average in the United States | — | 2601 |

The following analyses of bituminous and anthracitic coal will be sufficient to show the differences between them :—

| Locality. | Name of Coal. | Carbon. | Volatile Matter. | Ashes. |
|---|---|---|---|---|
| | *Bituminous.* | | | |
| Birtley Works, Newcastle-on-Tyne | | 60·50 | 35·50 | 4·00 |
| Alfreton, Derbyshire | | 52·46 | 42·50 | 2·04 |
| | *Anthracite.* | | | |
| Neath Abbey | Pwlferon Vein, 5th bed | 91·08 | 8·00 | 0·92 |
| Swansea | Peacock Coal | 89·00 | 7·50 | 3·50 |
| Ystalyfera | Brass Vein | 92·46 | 6·04 | 1·50 |
| Cwm Neath | Nine-feet Vein | 93·12 | 5·22 | 1·50 |
| France | Anthracite, common | 79·15 | 7·37 | 13·25 |
| ,, | Côte-d'or | 82·60 | 8·60 | 8·80 |
| ,, | Mais Saize | 83·80 | 7·50 | 9·50 |
| Pennsylvania | Beaver Meadow | 92·30 | 6·42 | 1·28 |
| ,, | Shenoweth Vein | 94·10 | 1·40 | 4·50 |
| ,, | Black Spring Gap | 80·57 | 7·15 | 3·28 |
| ,, | Nealey's Tunnel | 89·20 | 5·40 | 5·40 |
| Massachusetts | Mansfield Mine | 97·00 | — | 3·00 |
| Rhode Island | Portsmouth Mine | 85·84 | 10·50 | 3·66 |
| Westphalia | Schafberg, Alexander Seam | 82·02 | 8·69 | 9·29 |

2. **Bituminous Coal** (Backkohle, Fettkohle).—This yields a caked coke of metallic lustre; the coke is full of blisters of larger or smaller size, and has a greater volume than the original coal.[*] Bituminous coal ignites more easily than the other kinds, on account of the amount of hydrogen it contains; it therefore produces the longest flame, and is particularly adapted for the production of illuminating gas; it is less fit for burning in grates, as owing to its property of swelling, it is liable to obstruct the grate, thus impairing the draught and necessitating a frequent opening of the grate bars. On the other hand, the small coal of this bituminous kind is well adapted for this purpose, whilst non-bituminous coal, in small pieces, is perfectly useless, as it falls through the grate bars. This kind of bituminous coal is likewise well suited for forges (forging coal), as it swells before the tuyere, and thus forms a vault, in which the heat concentrates. The cannel coal of Lancashire and Scotland is chiefly used for the production of illuminating gas; the bituminous coal of Northumberland and Durham, which in commerce is frequently termed Newcastle coal, is of two

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[*] Erdm., Journ. f. pr. Ch., vii., 1,

kinds, one, rich in carbon, produces a short flame but a high yield of coke, and is rarely fit for forging purposes; the other, similar to the Westphalian coal, is richer in flame, and well adapted for heating boilers.

According to Regnault, the bituminous coal of Newcastle and Lancashire contain:—

| | | |
|---|---|---|
| Carbon . . . . | 85·81—89·19 | per cent |
| Hydrogen . . . | 5·31— 5·85 | ,, |
| Oxygen . . . . | 5·56— 8·34 | ,, |

The Westphalian coal is mostly bituminous, being anthracitic only in the lowermost seams. It is well adapted for heating boilers, for household purposes, for the production of coke, for forges, and partly also for the production of illuminating gas. This coal is raised from the pits mostly in small pieces (Gruskohlen) which cake when burnt on grates. According to Peters, they contain in 100 parts of organic substance:—

| | | |
|---|---|---|
| Carbon . . . . . . . . | 85·4 | per cent |
| Hydrogen . . . . . . | 5·1 | ,, |
| Oxygen and Nitrogen . . | 9·5 | ,, |

The specific gravity of bituminous coal is 1·2983, and that of the anthracitic kind 1·3647. The Prussian measurement of coal termed "Scheffel" comprises 1¼ Prussian cubic feet, and weighs 104·77 Prussian lbs.; it contains 70·4 per cent of compact coal.

The bituminous coal occurring near Dresden contains, according to Stein:—

| | | |
|---|---|---|
| Carbon . . . . . | 80·4 | per cent |
| Hydrogen . . . . | 4·6 | ,, |
| Oxygen . . . . . | 14·6 | ,, |
| Nitrogen . . . . | 0·11—0·77 | ,, |

According to Regnault, the bituminous coal of France has the following composition:—

| | | |
|---|---|---|
| Carbon . . . . . | 85·00—90·50 | per cent |
| Hydrogen . . . . | 4·88— 5·85 | ,, |
| Oxygen . . . . . | 4·53— 9·36 | ,, |

This kind of coal yields, on dry distillation, a compact caked coke of darkish colour, frequently with a metallic lustre on the surface. This coal is termed in German "Sinterkohlen," and is well adapted for burning on grates, for cupola furnaces, and for all those purposes requiring a low but continued temperature.

The coal of Upper Silesia is for the most part but slightly bituminous; they cake a little, however, and yield a flame; their composition is, according to Peters:—

| | |
|---|---|
| Carbon . . . . . . . . | 79·2 per cent |
| Hydrogen . . . . . . . | 5·1 „ |
| Oxygen . . . . . . . . | 15·7 „ |

The coal of Zwickau (Saxony) belongs to this kind, and contains, according to Stein, in 100 parts of dry coal free from ash:—

| | |
|---|---|
| Carbon. . . . . . . | 83·5 per cent |
| Hydrogen . . . . . | 4·8 „ |
| Oxygen. . . . . . . | 11·3 „ |
| Nitrogen . . . . . . | 0·09—0·68 „ |

French coals, of this kind, contain, according to Regnault:—

| | |
|---|---|
| Carbon . . . . . | 82·92—84·56 per cent |
| Hydrogen . . . . | 5·23— 5·32 „ |
| Oxygen . . . . . | 10·12—11·78 „ |

The coal which the Germans term "Sandkohlen," is very rich in oxygen; it shrinks greatly on coking, whilst the remaining coke consists of small loose pieces, which are of little use. This coal is used for burning lime and bricks, roasting ores in heaps, &c.

Regnault found sand coal to contain:—

| | |
|---|---|
| Carbon . . . . . | 76·05—78·32 per cent |
| Hydrogen . . . . | 5·35— 5·84 „ |
| Oxygen . . . . . | 16·30—18·26 „ |

**Examination of the Different Kinds of Coal.**—The nature of coal may frequently be judged of by its external appearance. A full black colour, lively lustre, and great hardness, indicate a large amount of oxygen; a pitch-like lustre shows a small, and a glassy lustre, a somewhat larger amount of carbon: black colour, strong lustre, slight coherence, and little tenacity, indicate the presence of a large amount of carbon, and also that the amount of hydrogen exceeds that of oxygen; brownish black colour, dull appearance, strong coherence, and a certain hardness indicate a small amount of carbon, whilst the amount of oxygen exceeds that of hydrogen.

**Washing Coal.**—A mechanical preparation is now and then employed to free the coal from intermixed slate and iron pyrites.* The following apparatus are described by Ure.†

M. Bérard was the inventor of a very successful apparatus for purifying small coal. He exhibited his arrangement at the Great Exhibition of 1851, receiving the council medal. The decoration of the Legion of Honour and a gold medal were also awarded to him at the Paris Exhibition of 1855. This apparatus which we shall presently describe, effects, without any manual labour, the following operations:—

1. The sorting the coal by throwing out the larger pieces.
2. Breaking the coal which is in too large pieces to be subjected to the operation of washing.
3. Continuous and perfect purification of the coal.
4. Loading the purified coal into waggons.
5. Loading the refuse (pyrites or schist) into waggons for removal.

The power required for the apparatus is that of from four to five horses, and the machine can operate upon from 80 to 100 tons of coal in about 12 hours if fitted up near the colliery. The expense of the operation of purifying is stated to consist solely in the wages of the workmen who conduct the labour of the machine.

The following description of Figs. 75 and 76 will render the arrangements of M. Bérard's machine readily intelligible:—

The coal is carried from the mine on a staging, for example, and the tram-waggon, B, is unloaded into a hopper, C, either by opening the bottom, or by tilting it (as in the position represented by the dotted lines, *b*) by means of a lever. It falls

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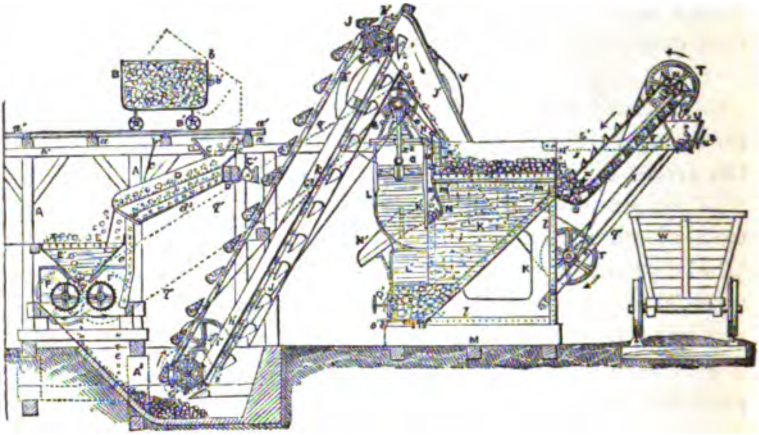
* Dingl., cxxvi., 11; cxviii., 265. Bgwkfd., iv., 270. Ann. d. Min., 4 sér., xvii., 381. Lampadius, Fortschr., p. 36. B. u. h. Ztg., 1853, p. 94. Methode von Meynier, B. u. h. Ztg., 1857, No. 28. Kohlenaufbereitung im Loirebecken, B. u. h. Ztg., 1859, No. 8. Hartm., Fortschr. im met. Hüttengew., i., 18; ii., 124 de 1858 et 1859.

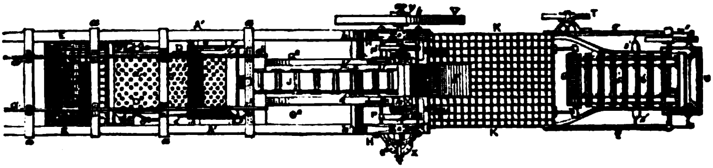
† Ure's Dictionary of Arts and Mines, vol. iii., p. 1012. Methode von Berard, B. u. h. Ztg., 1857, No. 13.

FIG 75.



afterwards either on the table or a movable grating, D, formed of frames or of a series of stages, of sloping perforated plates, which immediately sorts it into as many sizes as there are perforated plates.

FIG. 76.



This grating is suspended out of perpendicular by four chains or iron rods, C, C, fixed to the framework of the staging, A. It is moved by means of a cam motion (an arrangement of a cam and tongue mentonnet), C′, and falls back by its own weight against the stops, which produce concussions or vibrations favourable to the clearing out of the holes, and to the descent of the materials. The motion communicated to the grating admits of a much less inclination being given to it than would be the case if it were fixed.

The sorting is effected more quickly and perfectly, besides which, the differences of level, which it is necessary to preserve, are maintained.

The larger pieces rejected by the first plate reach the picking table, B, where a labourer picks out the largest stones and extraneous substances, such as fragments of castings, iron, &c.

The fragments which have passed through the upper plate, and are retained by that below, descend directly to the crushers, F, F′, situated below. Lastly, the fine portions of the coal which have passed through the second perforated plate fall upon a solid bottom, A′, whence they are thrown and delivered direct into the pit by means of a fixed shoot, *e*.

The crushing cylinders, F, F′, are made with a covering of cast-iron, mounted on an iron shaft. This covering can be easily replaced when worn out. On its surface it has small grooves, which are usually placed longitudinally, parallel with the axis of the cylinder, in order to avoid the slipping of the substances operated on. But it is also necessary to crush fragments of slate which gain admission with the coal, and these consisting of thin flattened laminæ, it would be necessary to bring the crusher closer than would be required to reduce the coal, which is of a more cubical form, to the proper size.

In order to obviate this difficulty, another series of grooves are formed on the surfaces of the crusher, transversely to those already described, the intersection of the two producing projections in the form of quadrangular pyramids with slightly rounded tops. In coming between the projections of the crushers, the fragments of slate, being unable to pass, are broken up without reducing the coal to a smaller size than is required.

When the coal has undergone a preliminary sifting, which has removed all the pieces exceeding 6 or 7 centimetres in size, one pair of crushers is sufficient. In that case, the grating may be dispensed with altogether by discharging the coal directly into the pit, and returning from the sifter to the washer the pieces of coal which have not been able to pass beyond the first perforated plate.

The small coal resulting from the washer or from the sifter, by means of the jigger, is delivered into a common pit placed under the washers. The pit is shaped like an inverted quadrangular pyramid, the three faces of which are inclined to one another at an angle of 45°, to facilitate the descent of the substance, and the fourth is usually vertical. It is on the latter that an opening is made, which is regulated by a flood-gate.

An elevator formed of an endless chain, with buckets, raises the coal from the bottom of the pit, and places itself sufficiently high to allow of the final discharge, which may take place into the waggon.

The rate of ascent of the buckets, and their capacity, are calculated so as to raise 160 to 200 tons of coal in the working hours, but this quantity may be diminished by means of the flood-gate in the pit.

The coal discharged by the elevator falls on the sorter, which ought immediately to divide it according to size, and distribute it to the ferry-boats.

The classifier is formed of a kind of oblong rectangular chest made of iron plates, in the inside of which are placed stages of perforated plates, the apertures in which decrease in a downward direction. Sufficient space is allowed between each plate for the motion of the materials. At the bottom of the perforated plates inclined planes are disposed, for throwing on one side the product of the sifting, which escapes through a slope made on the side of the sifter. A bottom fixed to the classifier itself, and, like it, movable, receives the dust in the finest numbers, if the sifting has been effected in the dry way, or else this bottom is immovable or fixed to longerons which support the classifier, if the sifting take place in water, as we are about to point out.

The classifier is suspended by two or three pairs of articulated handles, turning on axles fixed to longerons; by this means it enjoys an extreme freedom of motion in a longitudinal direction. A rapid reciprocating motion is communicated by a "bielle," which receives the action of a bent axle firmly established on a foundation fixed on the principal wall of the chamber of the machine. The rotatory motion is communicated to the axle by the disposition of an iron *pinion d'angle* working into *a*.

The *bac* is formed of a rectangular cast-iron chest, L′, one part of the bottom of which is inclined at 45°, the lower parts remaining horizontal.

Opposite one of the lesser sides of the rectangle, a cylinder, O, is placed, opening into the oblong chest at about half its height. The chest, L′, is prolonged under the cylinder, in order to increase the stability of the system, and the capacity of the drain-well (puissard).

A cast-iron box, M, M′, is firmly fixed in the interior of the bac, on flanges of cast-iron with vertical faces. This box has a slight inclination from M towards M′. It is covered with a perforated plate, usually of copper, fastened to the frame by a number of iron pins or bolts easy of replacement. The size of the holes varies according to that of the matters brought into the bac.

A cast-iron door, N, opening outward, is fixed slightly above the frame, serving as a kind of partition to divide the materials in the bac, and against it a flood gate, N′, is placed, by means of which the opening beneath the cast-iron door may be closed at pleasure.

A counter flood-gate, N′, is placed at the lower extremity of the frame; in raising it, a barrier is formed at any height that may be desired, by means of which the substances between the flood-gate and counter flood-gate may be arrested.

A piston, C, receives from the machine a sufficiently rapid reciprocating motion.

When everything is thus arranged, supposing the bac to be filled with water to the level of the front face at N′, and that the substances to be washed fill the space in the bac between this level and the perforated plate of the frame, the piston working upwards and downwards will press the water in the body of the cylinder, and will force it, by its incompressibility, to pass through the holes in the perforated plate; it will establish above this plate an ascending current, which, if of sufficient power, will raise the substances submerged.

The resistance to the rise of each body will be in proportion to its specific gravity, and the height it will be carried will follow an inverse law, supposing the fragments to be of nearly equal sizes.

The slates which fall over the counter flood-gate fall into a pocket or reservoir, N, whence they are discharged on opening a flood-gate, K′. Pressed by the upper column of water, they slide, with a slight admixture of water, on an inclined plane, K′, N′, which can be pierced with holes; the water escapes, and the slate only falls directly into the waggon of discharge.

The bent axle of transmission, S, S, moves in a groove, turning on a pivot at its extremity. The rotation of the axle communicates an oscillating motion to it.

The deposit formed in the drain-well is emptied through an opening of the flood-gate, placed at the lower part. An opening, serving as a man-hole, is reserved for effecting internal repairs without the necessity of raising the frame.

All coal contains a portion of earthy matters or impurities, which, in the form of bands or scales, are generally in some degree apparent to the eye, and constitute the ashes and clinker left by combustion. The small coal which is sent out of the mines necessarily contains a still larger proportion, frequently exceeding 10 per cent, consisting chiefly of shale and iron pyrites derived from the roof or floor of the seam of coal, or from the bands of impurities interstratified with it. Generally, these impurities are so incorporated with the mass of coal, that it must be crushed in order sufficiently to detach them. The pyrites which contains nearly the whole of the sulphur found in coal seams, are well known to be very injurious either in a heating or smelting furnace, in the manufacture or working of iron, in gas making, in coking, and other processes.

Many seams of coal already sunk to, or portions of seams in work, are left underground as unsaleable, in consequence of the impurities they contain. Small coal sells at a low price, chiefly in consequence of its impurities, and the defective coking property which they occasion. It has been estimated that an amount not far short of the quantity of coal sold, is sacrificed in producing a commercial article of adequate quality and description. The enormous consumption of coal in this country, amounting to nearly 100,000,000 tons per annum, renders the utilisation of a larger portion of the more valuable seams now in course of being exhausted, and the bringing into the market of other seams, objects of national importance.

The differences between the specific gravities of coal and its impurities, allow of their being separated by the action of water when sufficiently crushed. The water process hitherto most commonly adopted is that known as "jigging," which consists in forcing the water alternately up and down through the mass of coal. The downward current of water in "jigging" is prejudicial, and entails a large sacrifice of the finer particles of the best coal, whilst the upward current from its rapidity and irregularity, is costly both in time and power, besides failing to effect the more perfect separation which is obtained by a slow, continuously ascending or pulsating current, regulated to the proportion of shale in the coal, and to the size of the particles to be acted upon.

Mackworth's patent coal purifier is likewise described in Ure's "Dictionary of Arts and Mines," vol. iii., p. 1015.

In the late Mr. Herbert Mackworth's purifier (Fig. 77) the water ascends with a velocity of an inch or two in a second. It is sufficient to keep the particles in constant agitation, and the area of the separator can be reduced to a small fraction of its former size. The coal is supplied into the machine in a uniform stream, and as it is purified is raised out of the water on to a perforated plate, and delivered by the coalsweep into a long perforated shoot, down which it descends into the tram or waggon placed to receive it. The purified coal is thus obtained for coking or other purposes in a comparatively dry state. The shale which has, during the separation, accumulated in the shale-box, will discharge itself into another tram without stopping the machine, if the shale valves are first closed by the valve lever before throwing open the shale door. The pump, or agitator, is capable of throwing from 50 to 200 gallons of water per minute, according to the size of the machine. The endless band raises or lowers the coal from the hopper, into which the coal trams are tipped.

The advantages of the machine may be thus summed up:—

1. The more perfect separation of the impurities. If the coal is not sufficiently crushed, even the fragments of it containing shale or pyrites can be separated, as well as the shale, by regulating the velocity of the water. By increasing the speed of the machine and the velocity of the water, the separation of the impurities may be limited to any extent desired.

2. The saving of coal. This may be estimated at from 6d. to 1s. 6d. per ton. The ordinary washing processes sacrifice more than 20 per cent in weight, of which more than one-half is the best coal. In this machine the water does not pass out, but is used over and over again in a continuously circulating stream. The loss of coal does not exceed 2 per cent, and is generally under 1 per cent.

3. The economy in the power required to work the machine. One-horse power will suffice to work a machine with pump and elevator capable of purifying 50 tons of coal per day.

4. The saving in manual labour.

5. The quantity of water required is comparatively insignificant. A small supply of water is needed to replace that absorbed by the wetting of the shale and coal.

6. The coal is delivered drier than by any other existing process.

7. The largest machine stands in an area of 9 feet square, and motion can be obtained from any existing engine by a strap to a pulley making forty revolutions per minute, at a height of about 12 feet above the ground. The height given to the machine is for the purpose of passing trams underneath it, to receive the purified coal and shale as they are delivered. The machine requires no foundation, and is easily movable.

8. The great economy of the process, in every point of view, is important to—

**The Coke Trade.**—Many coals which never coked before will do so when deprived of their impurities, and the quality of every description of coke may be greatly improved. In coals above the average in quality, it has been found that the clinker may, by water purification, be reduced by four-fifths in quantity. The two principal sources of clinker—the whitish scales of carbonate of lime and the iron pyrites—are removed. A coke more uniform in texture and better in appearance is produced, and different descriptions of coal may be simultaneously mixed and purified by this machine. A cost of 3d. per ton on the coke will remove those impurities for which the consumer now pays at the same rate with the coke itself. An increase in the make and quality of the iron results from using purified coke in blast furnaces.

**Persons using Steam.**—The amount of ash and clinker from the coal, by no means represents the full amount of loss and waste occasioned by them. The coal is imperfectly burnt, and the fire-bars are injured. By removing the impurities, much of the labour in attending boiler fires may be spared, and the steam kept up more regularly. In steamers, and whenever the freight of coal is heavy, these advantages are peculiarly important.

**Gas Companies.**—Gas may be produced comparatively free from sulphur, as well as a purer and more valuable coke. By a small addition to the cost of the machine, the coal may be delivered in a dry state.

**Smiths and Workers in Metal.**—A coal purer than the large coal is produced. Better work and metal, and cleaner hearths are the result. Smiths are paying, in many instances, nearly double the former prices, for coal which has been purified. In puddling and other furnaces, the advantages of pure coal have been well ascertained.

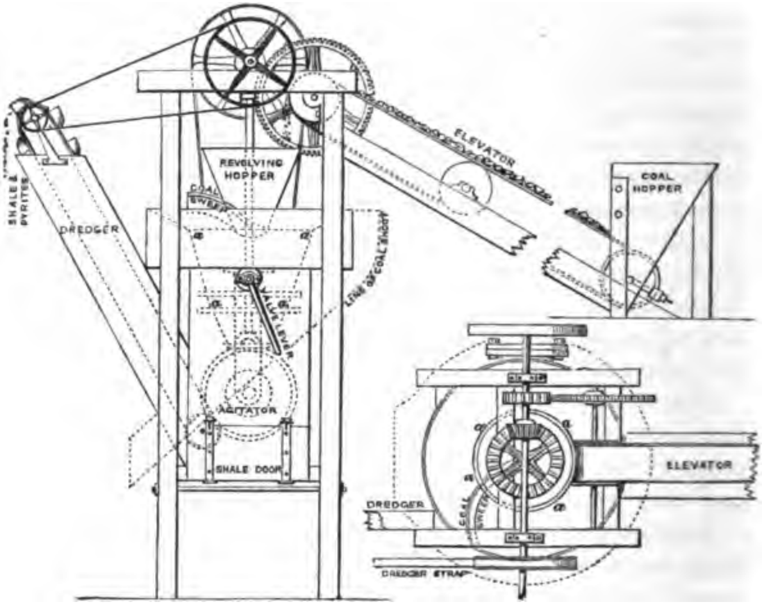
**Patent Fuel Companies.**—In all cases where freights are heavy, and the manipulations of the fuel costly, purity in the raw material is essential.

**Colliery Owners.**—Coal and shale, in lieu of being thrown into the gob, can be brought out of the mine, and separated for from 1s. to 2s. per ton, including haulage, &c. Crop coal, old pillars, and creeps may be turned to account.

The spontaneous combustion in the wastes of some mines may be prevented by bringing out the whole of the small coal and pyrites at a price which is now remunerative. New coal seams may be brought into the market, to the benefit both of the producer and the consumer.

In working this machine, the coal tram is tipped into the coal hopper; it is thence conveyed by the elevator in a continuous stream into the machine, and the purified coal is delivered uninterruptedly into a tram, whilst the shale and pyrites are delivered in a continuous manner by the dredger, or Jacob's ladder. The workman has only to attend to the placing of these waggons, and to regulate the amount of opening of the valves which allow the shale to descend into the shale box after it is separated.

Fig. 77



By means of the revolving hopper the coal passes gradually down into the separator, where a slow current of water is driven upwards through the mass of shale and coal, at a velocity of from 4 to 5 feet per minute, by the agitator or screw. This water passes back again by the finely perforated plate, and, with the fine silt suspended in it, is again driven upwards by the screw to undergo a repetition of the process. The gentle agitation produced by this current separates the shale and pyrites from the coal in the separator; the two latter descend through the valves and are taken up by the dredger, whilst the former is pushed upwards out of the water by the curved arm, and as soon as the water has drained off, the coal falls on to the shoot, which conducts it to the tram. A brush following the arm helps to keep the holes in the perforated plate open. The valves remain constantly more or less open, according to the indications given by the dredger, and are regulated by the valve lever. The water required to replace that absorbed by the dry coal and shale enters by the hopper, and flows slightly inwards through the shale valves as the shale is coming out.

The objects said to be obtained by the machine are—

1. A more perfect separation of the impurities than by jigging or buddling processes.
2. A saving of from 5 to 15 per cent of coal.
3. Economy of power and manual labour.
4. Saving of water and the delivery of the coal in a drier state.

Machines have been established in Scotland, Cumberland, Derbyshire, Gloucestershire, and Wales to purify from 20 to 100 tons of coal per day, at a cost not exceeding 3d. per ton, and with a loss not exceeding 2 per cent of coal.

**Composition, Heating Power, and Specific Gravity of Coal.**—The following table shows the composition,* heating power,† and specific gravity of various kinds of coals:—

| | Composition. | | | | | Heating Power. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kinds of Coal. | Carbon. | Hydrogen. | Chem. Com. Water. | Hygroscopic Water. | Ash. | Absolute. | Specific. | Pyrometric. | One part reduces Lead. | One part heats Water of 0° up to 100° C. | Specific Gravity. |
| As | | | | | | | | | | | |
| Anthracite .. | 85 | 3 | 2 | 5 | 5 | 0·96 | 1·44 | 2350° | 26—33 | 60·5—74·7 | 1·41—1·50 |
| Bitum. Coal .. | 78 | 4 | 8 | 5 | 5 | 0·93 | 1·17 | 2300° | 23—31 | 52·8—72·0 | 1·13—1·36 |
| Sinter-Coal .. | 75 | 4 | 11 | 5 | 5 | 0·89 | 1·16 | 2250° | 19—27 | 44·0—61·6 | 1·13—1·30 |
| Sand-Coal .. | 69 | 3 | 18 | 5 | 5 | 0·79 | 1·06 | 2200° | 21—31 | 50·0—71·0 | 1·05—1·34 |

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* Erdm., J. f. pr. Ch., vi., 205; xi., 165; xiii., 73, 143. Dingl., xi., 128; xiv., 500; xxi., 277; xxxix., 409; xlv., 235; xlvii., 150; cx., 212, 263, 287. Regnault, in Ann. d. min., 3 R., xii., 161. Marsilly, in B. u. h. Ztg., 1858, p. 249. Untersuchung der Kohlen mittelst des Löthrohrs, B. u. h. Ztg., 1859, p. 169.

† Scheerer's Met., i., 189. Dingl., lxxv., 48.

The calorific values of a variety of British coal, as tried under circumstances considered to be the most favourable for the development of heat, will be found in the following table :*—

| Name or Locality of Coal. | Actual number of lbs. of Water converted into steam by 1 lb. of Coal. Practical. | Number of lbs. of Water converted into steam by the Coke left by the Coal. Theoretical. | Total number of lbs. of Water convertible into steam by 1 lb. of the Coal. Theoretical. | Amount of Ammonia corresponding to Nitrogen contained in the Coal. | Amount of Sulphate of Ammonia corresponding to the Nitrogen contained in the Coal. |
|---|---|---|---|---|---|
| Graigola | 9·35 | 11·301 | 13·563 | 0·497 | 1·932 |
| Anthracite (Jones and Co.) | 9·46 | 12·554 | 14·593 | 0·225 | 0·990 |
| Old Castle Fiery Vein | 8·94 | 10·601 | 14·936 | 1·590 | 6·175 |
| Ward's Fiery Vein | 9·40 | — | 14·614 | 1·238 | 4·808 |
| Binea | 9·94 | 11·560 | 15·093 | 1·586 | 6·741 |
| Llangenneck | 8·86 | 10·599 | 14·260 | 1·299 | 5·044 |
| Pontrepoth | 8·72 | 10·873 | 14·838 | 0·218 | 0·848 |
| Pontrefellin | 6·36 | 10·841 | 13·787 | trace | — |
| Powell's Duffryn | 10·149 | 11·134 | 15·092 | 1·760 | 6·835 |
| Mynydd Newydd | 9·52 | 9·831 | 14·904 | 1·808 | 7·340 |
| Three-quarter Rock Vein | 8·84 | 7·081 | 13·106 | 1·299 | 5·044 |
| Cwm Frood Rock Vein | 8·70 | 8·628 | 14·788 | 1·347 | 5·232 |
| Cwm Nanty Gros | 8·42 | 8·243 | 13·932 | 1·919 | 7·448 |
| Resolven | 9·53 | 10·234 | 13·971 | 1·675 | 6·505 |
| Pontypool | 7·47 | 8·144 | 14·295 | 1·639 | 6·364 |
| Bedwas | 9·79 | 8·897 | 14·841 | 1·748 | 6·788 |
| Ebbw Vale | 10·21 | 10·441 | 15·635 | 2·622 | 10·182 |
| Porth Mawr Rock Vein | 7·53 | 6·647 | 12·811 | 1·554 | 6·033 |
| Coleshill | 8·00 | 6·468 | 12·799 | 1·785 | 6·930 |
| Dalkeith Jewel Seam | 7·08 | 6·239 | 12·313 | 1·214 | 0·471 |
| Dalkeith Coronation | 7·71 | 6·924 | 12·772 | trace | — |
| Wallsend Elgin | 8·46 | 6·560 | 13·422 | 1·712 | 6·647 |
| Fordel Splint | 7·56 | 6·560 | 13·817 | 1·372 | 5·327 |
| Grangemouth | 7·40 | 7·292 | 13·692 | 1·639 | 6·364 |
| Broomhill | 7·30 | 7·711 | 14·863 | 2·234 | 8·674 |
| Park End Lydney | 8·52 | 6·567 | 13·257 | 1·477 | 9·617 |
| Slievardagh | 9·85 | 10·895 | 12·482 | 0·279 | 1·084 |

The following table† shows the mean composition of average samples of coals :—

| Name of Coal. | Specific Gravity. | Carbon. | Hydrogen. | Nitrogen. | Sulphur. | Oxygen. | Ash. | Percentage of Coke left by each Coal. |
|---|---|---|---|---|---|---|---|---|
| *South Wales* :— | | | | | | | | |
| Ebbw Vale | 1·275 | 89·78 | 5·15 | 2·16 | 1·02 | 0·39 | 1·50 | 77·50 |
| Merthyr | 1·300 | 90·12 | 4·33 | 1·00 | 0·85 | 2·02 | 1·68 | 86·53 |
| Bedwas | 1·320 | 80·61 | 6·01 | 1·44 | 3·50 | 1·50 | 6·94 | 71·70 |
| Plymouth Works | 1·350 | 88·49 | 4·00 | 0·46 | 0·84 | 3·82 | 2·39 | 82·25 |

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* Ure's Dictionary of Arts and Mines, vol. i., p. 762.

† Ibid., p. 763.

| Name of Coal. | Specific Gravity. | Carbon. | Hydrogen. | Nitrogen. | Sulphur. | Oxygen. | Ash. | Percentage of Coke left by each Coal. |
|---|---|---|---|---|---|---|---|---|
| *South Wales*:— | | | | | | | | |
| Resolven | 1·320 | 79·33 | 4·75 | 1·38 | 5·07 | included in ash | 9·41 | 83·90 |
| Neath Abbey | 1·310 | 89·04 | 5·05 | 1·07 | 1·60 | — | 3·55 | 61·42 |
| Llynvi | 1·280 | 87·18 | 5·06 | 0·86 | 1·33 | 2·53 | 3·04 | 72·94 |
| Llangennoch | 1·312 | 85·46 | 4·20 | 1·07 | 0·29 | 2·44 | 6·54 | 83·69 |
| Pontypool | 1·320 | 80·70 | 5·66 | 1·35 | 2·39 | 4·38 | 5·52 | 64·80 |
| *Newcastle*:— | | | | | | | | |
| Willington | — | 86·81 | 4·96 | 1·05 | 0·88 | 5·22 | 1·08 | 72·19 |
| Haswell Wallsend | 1·286 | 83·47 | 6·68 | 1·42 | 0·06 | 8·17 | 0·20 | 62·70 |
| Hedley's Hartley | 1·310 | 80·26 | 5·28 | 1·16 | 1·78 | 2·40 | 9·12 | 72·31 |
| Carr's Hartley | 1·250 | 79·83 | 5·11 | 1·17 | 0·82 | 7·86 | 5·21 | 60·63 |
| N. Percy Hartley | 1·250 | 80·03 | 5·08 | 0·98 | 0·78 | 9·91 | 3·22 | 57·18 |
| Broomhill | 1·250 | 81·70 | 6·17 | 1·84 | 2·85 | 4·37 | 3·07 | 59·20 |
| *Derbyshire*:— | | | | | | | | |
| Elsecar | 1·296 | 81·93 | 4·85 | 1·27 | 0·91 | 8·58 | 2·46 | 61·60 |
| Park Gate | 1·311 | 80·07 | 4·92 | 2·15 | 1·11 | 9·95 | 1·80 | 61·70 |
| Butterley Portland | 1·301 | 80·41 | 4·65 | 1·59 | 0·86 | 11·26 | 1·23 | 60·90 |
| Staveley | 1·270 | 79·85 | 4·84 | 1·23 | 0·72 | 10·96 | 2·40 | 57·86 |
| *Lancashire*— | | | | | | | | |
| Ince Hall Arley | 1·272 | 82·61 | 5·86 | 1·76 | 0·80 | 7·44 | 1·53 | 64·00 |
| Balcarres Arley | 1·260 | 83·54 | 5·24 | 0·98 | 1·05 | 5·87 | 3·32 | 62·89 |
| Pemberton Yard | 1·348 | 80·78 | 6·23 | 1·30 | 1·82 | 7·53 | 2·34 | 60·60 |
| Rushy Park Mine | 1·280 | 77·76 | 5·23 | 1·32 | 1·01 | 8·99 | 5·69 | 56·66 |
| Cannel Wigan | 1·230 | 79·23 | 6·08 | 1·18 | 1·43 | 7·24 | 4·84 | 60·33 |
| Balcarres, 5-feet | 1·260 | 74·21 | 5·03 | 0·77 | 2·09 | 8·69 | 9·21 | 55·90 |
| Moss Hall New Mine | 1·278 | 77·50 | 5·84 | 0·98 | 1·36 | 12·16 | 3·16 | 57·70 |
| *Scotch*:— | | | | | | | | |
| Wallsend Elgin | 1·200 | 76·09 | 5·22 | 1·41 | 1·51 | 5·05 | 10·70 | 58·45 |
| Dalkeith Coronation | 1·316 | 76·94 | 5·20 | trace | 0·38 | 14·37 | 3·10 | 53·50 |
| Eglington | 1·250 | 80·08 | 6·50 | 1·55 | 1·38 | 8·05 | 2·44 | 54·94 |
| Dalkeith Jewel Seam | 1·277 | 74·55 | 5·14 | 0·10 | 0·33 | 15·51 | 4·37 | 49·80 |
| Grangemouth | 1·290 | 79·85 | 5·28 | 1·35 | 1·42 | 8·58 | 3·52 | 56·60 |
| *Sundry*:— | | | | | | | | |
| Bagillt | 1·269 | 88·48 | 5·62 | 2·02 | 1·36 | 0·86 | 1·62 | 55·80 |
| Ewlowe | 1·275 | 80·97 | 4·96 | 1·10 | 1·40 | 8·20 | 3·37 | 54·50 |
| Ibstock | 1·291 | 74·97 | 4·83 | 0·88 | 1·45 | 11·88 | 5·99 | 50·80 |
| *Borneo*:— | | | | | | | | |
| Labuan | 1·280 | 64·52 | 4·74 | 0·80 | 1·45 | 20·75 | 7·74 | — |
| Three-feet Seam | 1·370 | 54·31 | 5·03 | 0·98 | 1·14 | 24·22 | 14·32 | — |
| Eleven-feet Seam | 1·210 | 70·30 | 5·41 | 0·67 | 1·17 | 19·19 | 3·23 | — |
| *Van Diemen's Land*:— | | | | | | | | |
| Tingal | — | 57·21 | 3·58 | 1·20 | 1·32 | 7·80 | 29·09 | — |
| Tasman's Peninsula | — | 65·54 | 3·36 | 1·91 | 1·03 | 1·75 | 26·41 | — |
| Whale's Head | — | 65·86 | 3·18 | 1·12 | 1·14 | 7·20 | 21·50 | — |
| Adventure Bay | — | 80·22 | 3·05 | 1·36 | 1·90 | 4·80 | 8·67 | — |
| *Sydney* | — | 82·39 | 5·32 | 1·23 | 0·70 | 8·32 | 2·04 | — |
| *Formosa* | 1·240 | 78·26 | 5·70 | 0·64 | 0·49 | 10·95 | 3·96 | — |
| *Vancouver's Island* | — | 66·93 | 5·32 | 1·02 | 2·20 | 8·70 | 15·83 | — |
| *Conception Bay* | 1·290 | 70·55 | 5·76 | 0·95 | 1·98 | 13·24 | 7·52 | — |
| *Trinidad* | — | 65·20 | 4·25 | 1·33 | 0·69 | 21·69 | 6·84 | — |

The ash of coal,* which, in quantity, varies between 0·5 and 20 per cent, has the composition of brown coal ash, and is sometimes rich in sulphide of iron,† which impairs the applicability of the coal. Most kinds of coal contain as much as 5 per cent of ash, and about the same amount of hygroscopic water.

Owing to an admixture of clay slate, some coal contains a large quantity of potash.

The amount of ash, the size of the pieces, and of the vessels in which the coal is measured, as well as its texture and nature, influence the weight of a certain volume of this fuel. The value of the coal does not entirely stand in proportion to its weight or specific gravity, as the heating power of coal, which constitutes its relative value, depends also on other circumstances. In all cases, it is best to buy coal by weight, and not by volume, at the same time deducting an amount corresponding to the ash contained in the coal.‡

**Employment of Coal.**—Coal is frequently employed in metallurgical operations.‖ Sinter-coal or bituminous small coal is peculiarly adapted to firings on horizontal grates; anthracite coal is better burnt on step-grates,§ for which bituminous coal is not adapted. In order to ensure perfect combustion, the coal must not lie on the grate in too thick layers, the current of air must be sufficiently strong, and the fire must be suitably conducted to prevent the production of a smoky flame; and, according to the amount of ash contained in the coal, and to its caking nature, a more or less frequent opening of the grate will be required.

The effect of coal is frequently increased¶ by wetting it with water, or by admitting steam. Coal rich in oxygen evolves water in the form of steam, and thus produces a larger but less intense flame than coal poor in oxygen.

The employment of raw coal instead of coke in iron blast furnaces has caused a great economy in fuel, although the conduct of the blast furnace process is rendered more difficult by the caking of the coal with the ore mixture, or sometimes when anthracite coal is employed, it decrepitates and falls into small pieces, thus obstructing the furnace. In England, Scotland, and Wales, the anthracitic coal (sinter and sand coal) poor in ash, is successfully employed with the application of hot blast; whilst in France and Belgium large quantities of coal, similar to those occurring in England and Scotland, have not been found.

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* Pogg. Ann., lxxxiv., 67.
† Polyt. Centr., 1855, p. 1281. Plattner's Röstprocesse, p. 103.
‡ Berggeist, No. 100, 1859.
‖ Ibid., No. 99, 1859.
§ B. u. h. Ztg., 1856, p. 355.
¶ Bgwkfd., vii., 239. Dingl., lxvi., 316.

Raw coal is also employed in smelting lead and silver ores in cupola furnaces; anthracite is used, at Tarnowitz,* for smelting copper ores.

Attempts which have been made to use raw coal in admixture with charcoal or coke, for processes in cupola furnaces, have not always been successful.†

A too large amount of ash lessens the value of coal for application in cupola as well as in reverberatory furnaces. If the ash is refractory, non-fused lumps will be formed in cupola furnaces, and crusts on the grate bars; and if the ash does not fuse at all it will be carried away along with the draught, and be liable to render the smelting product impure.

Small coal and waste of other kinds of fuel are sometimes utilised by being mixed with a suitable cement (pitch) and moulded into bricks by pressure.

The following are the productions of this artificial or patent fuel made in this country:‡—

Wylam's patent fuel is small coal and pitch, moulded together into bricks by pressure. The pitch is obtained by the distillation of coal-tar, from which naphtha and a peculiar oil are separated, leaving the pitch. This pitch is finely ground and mixed with small coal; in this state it is passed, by a very ingenious application of the Archimedian screw, through a retort, maintained at a dull red heat, by which it is softened for being moulded; the moulding is effected by a kind of brick-making machine, under enormous pressure.

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* Erdm., J. f. pr. Ch., xv., 120, 293.

† Jahrb. f. d. sächs. B. u. Hüttenm., 1832, p. 135; 1834, p. 80; 1835, p. 158; 1837, p. 55; 1838, p. 53. B. u. h. Ztg., 1843, pp. 87, 683, 964. Bgwkfd., i., 335; ii., 9, 893; iii., 169; iv., 175; vi., 186; vii., 126; viii., 54, 460. Polyt. Centr., 1849, p. 362.

‡ Ure's Dictionary of Arts and Mines, vol. ii., 408.

Warlich's patent fuel is similar in character, but he adds a little common salt or alum to prevent the evolution of too much smoke, and the fuel bricks are subjected to a temperature of 400° F., for eight hours, by which the more volatile constituents are driven off.

Wood's fuel is prepared by mixing small coke or coal, in a heated state, with tar or pitch, in a common pug-mill, after which it is moulded in the ordinary manner.

Bessemer's process consists merely in exposing coal-dust to a temperature of 600° F. By this means, the bituminous part of the coal becomes softened, and the whole can be pressed into a firm block.

Grant's patent.—This fuel is composed of coal dust and coal-tar pitch; these materials are mixed together, under the influence of heat, in the following proportions:—20 lbs. of pitch to 1 cwt. of coal dust, by appropriate machinery, consisting of crushing rollers for breaking the coal in the first instance, sufficiently small to pass through the screen, the meshes of which are not more than a ¼ of an inch asunder; secondly, of mixing-pans or cylinders, heated to the temperature of 220°, either by steam or heated air; and thirdly, of moulding machines, by which the fuel is compressed, under a pressure, equal to 5 tons, into the size of a common brick; the fuel bricks are then whitewashed, which prevents their sticking together, either in the coal bunkers or in hot climates.

The advantages of these artificial fuels over coal may be stated to consist, first, in their efficacy in generating steam; secondly, in occupying less space, that is to say 500 tons of it may be stowed in an area which will contain only 400 tons of coal; thirdly, they are used with much greater ease by the stokers or firemen than coal, and they create little or no dirt or dust, considerations of some importance when the delicate machinery of a steam engine is considered; fourthly, they produce a very small proportion of clinkers, and thus are far less liable to choke and destroy the furnace bars and boilers than coal; fifthly, the ignition is so complete that comparatively little smoke, and only a small quantity of ashes, are produced by them; sixthly, from the mixture of the patent fuel, and the manner of its manufacture, it is not liable to enter into spontaneous ignition.

A great many other persons have either patented processes for the preparation of artificial fuel, or published suggestions. They are so nearly alike, that a few of them only require any notice.

Cobbold agitates peat in water to separate the earthy matter, and then allows the peat to subside, and consolidates it.

Godwin makes bricks of mud or clay with pitch or coal.

Oram employs tar, coals, or mud.

Hill takes the residuary matter, after the distillation of peat, and mixes it with pitch.

Holland mixes lime or cement with tar and small coals.

Ransome cements small coal together by a solution of silicate of soda.

On the Continent, Dehaynin and Hamoir,* in Belgium and Paris, produce bricks (Peras, or briquettes de charbon) from tar and small coal, and Popelin Ducarret† obtains artificial fuel, termed Charbons de Paris, or Charbon moulu, from coal-dust and tar; both kinds of bricks have come into repute.

From the Admiralty Coal Inquiry's Report we obtain the following analyses of several of the more important artificial fuels:—

| Name of Fuel. | Specific Gravity of Fuel. | Carbon. | Hydrogen. | Sulphur. | Oxygen. | Ash. |
|---|---|---|---|---|---|---|
| Warlich's . . . . | 1·15 | 90·02 | 5·56 | 1·62 | — | 2·91 |
| Livingstone's . . . | 1·18 | 85·07 | 4·13 | 1·45 | 2·03 | 4·52 |
| Lyon's . . . . . | 1·13 | 86·36 | 4·56 | 1·29 | 2·07 | 4·66 |
| Bell's . . . . . | 1·14 | 87·88 | 5·22 | 0·71 | 0·42 | 4·90 |
| Holland and Green's | 1·30 | 70·14 | 4·65 | — | — | 13·73 |
| Wylam's . . . . | 1·10 | 79·91 | 5·69 | 1·25 | 6·63 | 4·54 |

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* Bgwkfd., xviii., 66. B. u. h. Ztg., 1858, 269.

† Polyt. Centr., 1852, p. 509. B. u. h. Ztg., 1858, p. 269.

**Practical Results.**—1. The heating power of an ordinary good coal is, on an average, almost as large as that of charcoal, and twice as large as that of dry wood. In smelting processes it is generally adopted that the heating power of coal to that of wood stands in the proportion of five to one when compared by volume, and in the proportion of fifteen to eight when compared by weight.

2. Karsten states that in reverberatory furnaces—

100 cubic feet of coal are equal in effect to 700 cubic feet of wood, and
100 lbs. of coal are equal in effect to 260 pounds of wood;
and in boiling processes—
100 cubic feet of coal = 400 cubic feet of wood = 400 cubic feet of turf,
100 lbs. of coal = 250 lbs. of wood = 250 lbs. of turf.

3. According to Rosenthal, 1 cubic foot of coal is equal in heating power to 7·25 cubic feet of red beech, 7·14 cubic feet of white beech, 6·30 cubic feet of oak, 7·17 cubic feet of birch, 7·40 cubic feet of alder, from 6 to 7·5 cubic feet of fir, 8·95 cubic feet of willow, 11·50 cubic feet of aspen, and 13·14 cubic feet of poplar.

4. The Society for Promoting Industry in Prussia experimented on forty-eight kinds of Prussian coal, and determined that 1 lb. of the most inferior kind converted 6·10 lbs. of water of 0° into steam of 110—115° C., and 1 lb. of the very best kind 8·93 lbs. of water into such steam. When taking coal of the average of all forty-eight sorts, 7·33 lbs. of water were evaporated.

Johnson* has experimented, on a large scale, on North American coal, and Playfair and De la Beche have determined the practical value of various sorts of this fuel; on comparing both their results with those found in Prussia, it will be seen that they nearly correspond, as, on calculating Prussian weights, the most inferior kind of American coal evaporates 5·84 lbs. of water, and the most superior kind

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* Berggeist, 1859, Nos. 15, 66, 68, 70, 99. Ztschr. d. Ver. deutcher Ing., ii., 223.

8·99 lbs.; the most inferior English coal evaporated 5·30 lbs. of water, and the best kind 8·57 lbs.

These results are, according to Peters,* proportionate with those which are obtained by calculating the heating power from the elementary analysis of coal (page 332).

5. According to Peters,

| | | | | | |
|---|---|---|---|---|---|
| 50 kilos. | of coal from | Newcastle | yield | 90·2 | caloric units. |
| 50 | „ „ | Upper Silesia | „ | 84·8 | „ |
| 50 | „ „ | Westphalia | „ | 94·8 | „ |

6. 12 cubic feet (38 Pud) of Russian anthracite replace 343 cubic feet of oak wood. Anthracite, on heating, decrepitates more or less according to its manner of stratification; it is more inclined to decrepitate if it occurs in seams which dip at sharp angle, and less so if it be deposited in a flat position.

7. Brix† asserts that with wood, peat, and brown coal, the heating power is lowered by the large amount of oxygen, hygroscopic water, and partly ash, to nearly half the average heating power of coal; these three kinds of fuel can therefore only compete with coal if their price is lower by one half than the cost of that material. Charcoal and coke are about equal in effect to the average effect of the various coals.

In experiments with heating boilers, it was proved that wood yielded 70 per cent of the theoretical heating power, coal 66 per cent, good brown coal 62 per cent, and moist brown coal, as well as anthracitic coal, 56 per cent.

## COKE.

The intention of the process of coking coal is—

1. To concentrate the carbon which the coal contains, so that the coke may be capable of producing a higher temperature.

2. To remove the volatile substances which, on burning, chiefly for domestic purposes, have an unpleasant smell.

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* Berggeist, 1859, Nos. 68, 70. Schles. Wochenschr., 1859, No. 13.

† Berggeist, 1859, No. 66.

3. To deprive the coal of the property of becoming pasty at a high temperature, in iron blast furnaces, for instance, in consequence of which the blast cannot penetrate sufficiently, and the process of the furnace becomes disordered.

4. To remove part of the sulphur which coal frequently contains in the form of sulphide of iron.

The production of good coke requires a combination of qualities not very frequently met with in coal, and hence first rate coking coals can be procured only from certain districts.

The applicability of the coal depends chiefly on the amount and quality of ash* present. Coal which, on burning, leaves 5 per cent of ash remaining, is still useful for iron blast furnaces. Iron pyrites is a common obstacle to coke makers, as only part of the sulphur is removed by the process of coking, and one quarter or one-half of it always remains. This remainder either wastes the grate bars, boilers, &c., or impairs the smelting product.†

Calvert and Chenot employ common salt in the coking process for the removal of sulphur, and it has been proved that iron of excellent quality may be produced with coke which has been thus purified. Steam has been also successfully employed for the removal of sulphur.

Bleibtreu mixes small coal with at least its equivalent weight of pounded limestone, and cokes this mixture in the ordinary way. When the resulting coke is employed in iron blast furnaces, almost all the sulphur will combine with the lime. Coke, as well as coal, containing iron pyrites is liable to ignite spontaneously.

Sulphur contained in coal in the form of gypsum, cannot be removed by the process of coking, but is less injurious in the smelting of iron than sulphur contained in iron pyrites.

It has been before described that impurities of the coal may be separated by coal washing machines (page 457).

The coal is coked either in large or small pieces, and the apparatus applied are either heaps* (meiler), or mounds, or furnaces of variable construction.†

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* Berthier's Analyt. Met. Chem., i., 136. Erdm., J. f. pr. Ch., vii., 2.

† Bgwkfd., x., 522.

Fig. 78 represents a simple coking *meiler*, constructed in

FIG. 78.

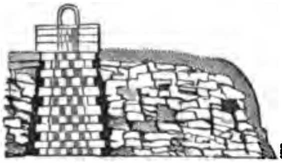
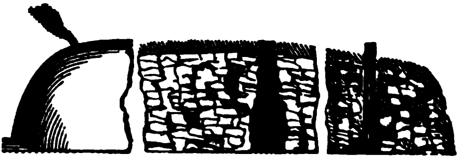


FIG. 79.



a circular form round a central chimney of loose bricks, towards which small horizontal flues are laid among the lumps of coals. The sides and top are covered with culm or slack, and the heap is kindled from certain openings towards the circumference.

Fig. 79‡ represents an oblong *meiler* sometimes made 100 or 150 feet in length, and from 10 to 12 feet in breadth. The section in the middle of the figure shows how the lumps are piled up. The wooden stacks are lifted out when the heap is finished in order to introduce kindlings at various points, and the rest of the meiler is then covered with slack and clay to protect it from the rain. A jet of smoke and flame is seen issuing from its left end.

If the coal is very impure, the heaps must be narrow, but if it is hard and pure, it may be coked in wide rows. It is advisable, in all cases, to perform the coking near the furnaces; even in the furnace yard, the transport does not form an objectionable consideration, because the yield of coke is universally at least half the weight of the coal, and in most instances more than that. Now, coke is comparatively more friable than stone coal, and its dust is worthless. The loss prevented by coking in the furnace yard, therefore, is more than sufficient to pay the higher cost of transporting coal from the mine to the furnace.

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* SCHEERER, Metall., i., 316. KNAPP, Chem. Techn., i., 46.

† DINGL., xxi., 533; xxv., 262; cxix., Heft. 4; cxxi., 97. Ann. d. min., 3 sér., xx., 3; 4 sér., xvii., 189. Polyt. Centr., 1850, p. 488. Engl. Oefen: Preuss. Ztschr., iii., Bd. 69. Belgische Oefen: B. u. h. Ztg., 1855, No. 25. Franz. Oefen: Bulletin de la Société de l'industrie Minérale, i., 434; ii., 284, 454. APPOLTS, Oefen: B. u. h. Ztg., 1856, Nos. 17, 45; 1859, Nos. 11, 18, 24. Polyt. Centr., 1859, No. 3. Vercoking in Oberschlesien, B. u. h. Ztg., 1857, No. 13; 1858, p. 194. HARTMANN, Aufbereitung und Vercoking der Steinkohlen: Weimar, 1858. HARTMANN, Fortschrittte des Eisenhüttengewerbes, 1858, p. 23. HARTMANN, Fortschritte des met. Hüttengewerbes, 1859, p. 163. Bgwkfd., iv., 477; v., 305; xii., 463; vii., 2. KARST., Arch., 1 R., 1., 81.

‡ URE's Dictionary of Arts and Mines, vol. i., p. 849. OVERMANN's Treatise on Metallurgy, p. 378.

In a row, such as is represented in Fig. 79, the coarse coal forms the skeleton of the heap inside, and, at distances of 8 or 12 feet, a kind of chimney is constructed with it. If coal coarse enough for the purpose can be obtained, a flue of loose fire-bricks is constructed over the whole length of the floor. Sometimes a longitudinal channel, and also cross channels are formed of wood, especially where it is cheap, and the chimneys likewise are constructed of sticks. The best plan generally is to form air channels through the bottom, and also the flues or chimneys, of coarse well-charred coke; these do not swell. They hold good fire, and cause no loss, for what is burnt in one kind of coal is saved in the other; besides, this method furnishes the best coke. One of these long heaps of coal is from 3 to 5 feet high according to the kind of coal; it consists of coarse coal covered with small coal, and, lastly, with slack, or slack and clay. Fire from wood or burning coke is applied to the foot of the pile at such distances as will secure its uniform distribution, and it is also applied in the immediate vicinity of the flues which lead to the chimneys, as these are most suitable for conducting it into the interior. One end of a pile may be kindled, and even burn out while the other end is building; coke may thus be formed in a short time. The collier must endeavour to conduct the fire into the interior as quickly as possible, and thus heat outwards from within; in fact, this operation must be performed on the same principle as in charring wood. But, since stone coal is less valuable than wood, and as a higher heat is required to drive off impurities, and also more fresh air and moisture to expel sulphur, the burning coal must necessarily be worked more openly, and under a more brisk heat, than wood. When the fire is well spread through the interior of the pile, and its progress is safe, the sides of the row are covered with coke dust, but the base and top are kept free so as to admit a lively combustion and a strong heat. In fact, if good coke is to be made, a large quantity of air, and, if possible, damp air, must pass through the coal at this time. After the lapse of about twenty-four hours, the heat is well distributed, and the flames on the comb of the pile disappear, and only hot invisible gases escape. The pile is now closely covered with coke dust and left to cool; this requires another twenty-four hours, so that in two days' time the coke is burnt and ready to be drawn.

Coarse coal fresh from the mines is best suited for this mode of coking; and, indeed, this method cannot be employed when the coal is fine, that is to say, when it consists mostly of slack, which is too close, and does not admit of the passage of sufficient air to form good coke. It is often charred by mixing it with small wood, chips, or bushes bound in faggots, but this is expensive, and where wood is scarce, cannot be resorted to. The coal is then charred in large heaps or pits like wood. Such a pit may be from 20 to 25 feet in diameter, and from 3 to 8 feet high, according to the quality of the coal.

The following figure* (80) represents a pit-kiln or schachtofen, which is sometimes used in Germany for coking coal:—

*a* is the lining made of fire-bricks; the enclosing walls are built of the same material; *b*, *b* is a cast-iron ring covered with a cast-iron plate, *c*. The floor of the kiln is massive. The coal is introduced, and the coke taken out, through an opening in the side, *d*; during the process it is bricked up and closed with an iron door. In the surrounding walls are four horizontal rows of flues, *e*, *e*, *e*, *e*, which are usually iron pipes. The lowest row is upon a level with the floor of the kiln, and the others are respectively one foot and a half higher than the preceding. Near the top of the shaft there is an iron pipe, *f*, of from 8 to 10 inches in diameter, which allows the incombustible vapours generated in the coking to escape into the condenser, which consists either of wood or brick chambers. For kindling the coal, a layer of wood is first placed on the bottom of the kiln.

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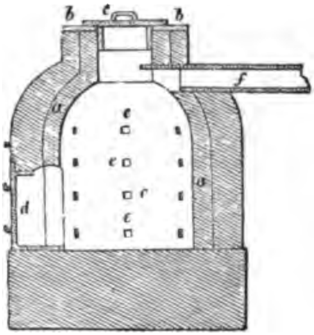
* URE's Dictionary of Arts and Mines, vol. i., 849.

FIG. 80.



The coking of small coal is performed upon vaulted hearths somewhat like bakers' ovens, but with still flatter roofs. Of such kilns several are placed alongside one another, each being an ellipse deviating little from a circle, so that the mouth may project but a small distance. The dimensions are such, that from 10 to 12 cubic feet of coal may be spread in a layer, 6 inches deep, upon the sole of the furnace. The top of the flat arch of fire-brick should be covered with a stratum of loam and sand.

Figs. 81 and 82 represent such a kiln, as it is mounted in Zabrze in Upper Silesia, for coking small coal. Fig. 81 is the ground plan; Fig. 82 the vertical section in the line of the long axis of Fig. 81. *a* is the sand bed of the hearth under the brick sole; *b* is the roof of large fire-bricks; *c*, the covering of loam; *d*, the top surface of sand; *e*, the orifice in the front wall for admission of the coal and removal of the coke over the sloping stone, *f*. The flame and vapours pass off above the orifice through the chimney marked *g*, or through the aperture, *h*, into a lateral chimney; *i* is a bar of iron laid across the front of the door as a fulcrum to work the iron rake upon. A layer of coals is first kindled upon the hearth, and when this is in brisk ignition, it is covered with the culm in successive sprinklings. When the coal is sufficiently coked, it is raked out and quenched with water.

FIG. 81.

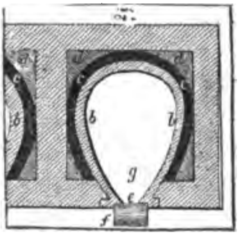
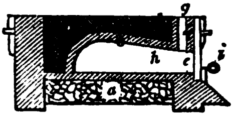
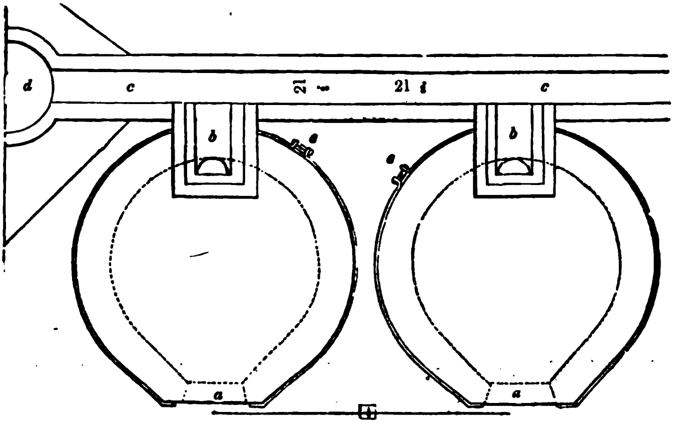


FIG. 82.



An excellent range of furnaces for making a superior article of coke, for the service of the locomotive engines of the

FIG. 83.



London and North-Western Railway Company, has been erected at the Camden Town station, consisting of eighteen ovens in two lines, the whole discharging their products of combustion into a horizontal flue, which terminates in a chimney stalk 115 feet high. Fig. 83 is a ground plan of the elliptical ovens, each being 12 feet by 11 internally, and having 3 feet thickness of walls. *a, a* is the mouth, 3½ feet wide outside, and about 2¾ feet within; *b, b* are the entrances into the flue. They may be shut more or less completely by horizontal slabs of fire-bricks resting on iron frames, pushed in from behind to modify the draught of air. The grooves of these damper-slabs admit of a small stream of air, to complete the combustion of the particles of soot driven off; by this means the smoke is well consumed. The flue, *c, c*, is 2½ feet high by 21 inches wide. The chimney, *d*, at the level of the flue, is 11 feet in diameter inside, and 17 outside. *e, e* are the keys of the iron hoops which bind the brickwork of the oven. Fig. 84 is a vertical section in the line, A, B, of Fig. 83, showing at *b, b* and *e, e* the entrances of the different ovens into the horizontal flue, the direction of the draught being indicated by the arrows. *f, f* is a bed

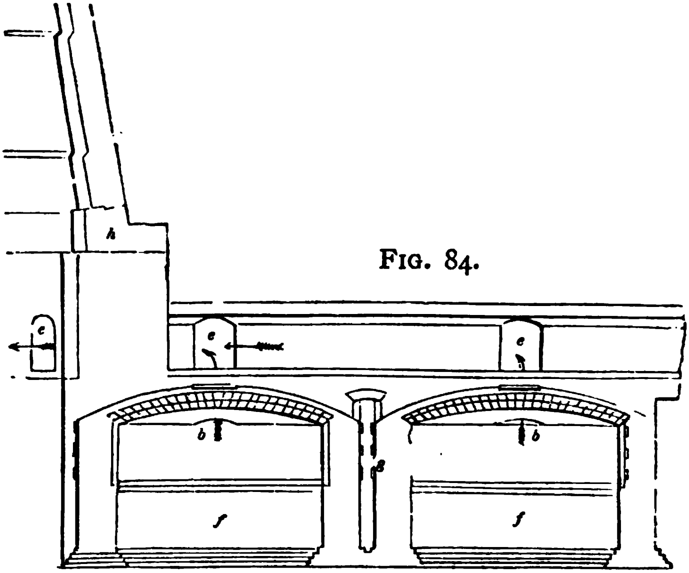
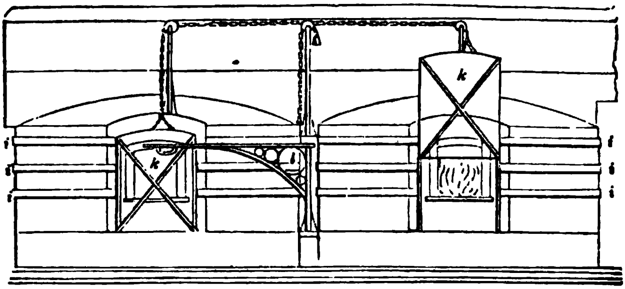


FIG. 84.

of concrete, upon which the whole furnace range is built, the level of the ground being in the middle of that bed. *g* is a stanchion on which the crane is mounted; *h* is a section of the chimney wall, with part of the interior to the left of the strong line. Fig. 85 is a front elevation of two of these coke

FIG. 85.



ovens, in which the bracing hoops, *i*, *i*, are shown; *k*, *k* are the cast-iron doors, strengthened outside with diagonal ridges, each door being 5½ feet high by 4 feet wide, and lined internally with fire-bricks. They are raised and lowered by means of chains and counter weights moved by the crane, *l*.

Each alternate oven is charged, between eight and ten o'clock every morning, with 3½ tons of good coals. A wisp of straw is thrown in on the top of the heap, which takes fire by the radiation from the dome (which is in a state of dull ignition from the preceding operation), and inflames the smoke then rising from the surface, by the reaction of the hot sides and bottom upon the body of the fuel. In this way the smoke is consumed at the very commencement of the process, when it would otherwise be most abundant. The coking process is in no respect a species of distillation, but a complete combustion of the volatile principles of the coal. The mass of coal is first kindled on the surface, where it is supplied with abundance of atmospheric oxygen, because the doors of the ovens in front, and the throat-vents behind, are then left open. The consequence is that no more smoke is discharged from the top of the chimney, at this, the most sooty period of the process, than is produced by an ordinary kitchen fire. Under these circumstances, the coal gas, or other gas, supposed to be generated in the slightly heated mass beneath, cannot escape combustion in passing up through the bright open flame of the oven. As the coking of the coal advances most slowly and regularly from the top of the heap to the bottom, only one layer is effected at a time, and in succession downwards, while the surface is always covered with a stratum of red-hot cinders, ready to consume every particle of carburetted or sulphuretted hydrogen gas, which may escape from below. The greatest mass, when calcined in this downward order, cannot emit into the atmosphere any more of the above-mentioned gases than the smallest heap.

The coke being perfectly freed from all fuliginous and volatile matters, by a calcination of upwards of forty hours, is cooled down to moderate ignition by sliding in the dampers, and sliding up the doors, which had been partially closed during the latter part of the process. It is now observed to form prismatic concretions, somewhat like a columnar mass of basalt. These are loosened by iron bars, lifted out upon shovels furnished with long iron shanks, which are poised upon swing chains with hooked ends, and the lumps are thrown upon the pavement, to be extinguished by sprinkling water upon them from the rose of a watering can; or they might be transferred into a large chest of sheet-iron, set on wheels, and then covered up. Good coals, thus treated, yield 80 per cent of an excellent compact glistening coke, weighing about 14 cwts. per chaldron.

The loss of weight in coking in the ordinary ovens, is usually reckoned at 25 per cent; and coal, which thus loses a quarter in weight, gains a quarter in bulk.

Labourers who have been long employed at rightly constructed coke ovens seem to enjoy remarkably good health.

Mr. Ebenezer Rogers, of Abercarn, in Monmouthshire, has lately introduced a new method of coking, which he thus describes:*—

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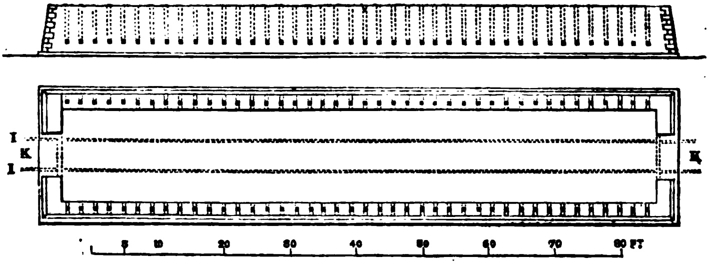
* URE's Dictionary of Arts and Mines, vol. i., p. 851.

"A short time ago, a plan was mentioned to the writer as having been used in Westphalia, by which wood was charred in small kilns; as the form of kiln described was quite new to him, it led him to some reflection as to the principles on which it acted, which were found so simple and effective, that he determined to apply them on a large scale for coking coal. The result has been that in the course of a few months the original idea has been so satisfactorily matured and developed, that instead of coking 6 tons of coal in an oven costing £80, 150 tons of coal are now being coked at once, in a kiln costing less than the former single oven.

Figs. 86 and 87.



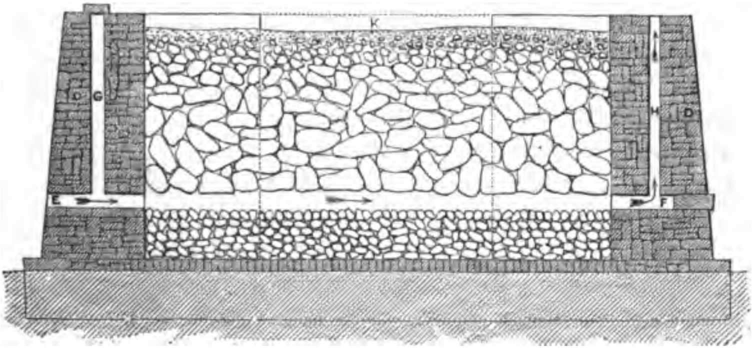


Fig. 88.

"Figs. 86 and 87 are a side elevation and plan of one of the new coking kilns on a small scale; Fig. 88 is an enlarged transverse section.

"D, D, are the side walls of the kiln, which are provided with horizontal flues, E, F, which open into the side or bottom of the mass of coal. Connected with each of these flues are the vertical chimneys, G, H. The dotted lines, I, I, Fig. 87, represent a movable railway, by which the coal may be brought into the kiln, and the coke removed from it. In filling the kiln with coal, care is taken to preserve transverse passages or flues for the air and gases between the corresponding flues, E, F, in the opposite walls. This is effected by building or constructing the passages at the time with the larger pieces of coal, or else by means of channels or flues permanently formed in the bed of the kiln. When the coal is of different sizes, it is also advantageous to let the size of the pieces diminish towards the top of the mass. The surface of the coal when filled in, is covered with small coal, ashes, and other suitable material.

"When the kiln is filled, the openings, K, at the ends, are built up with bricks, as shown dotted; the kiln is not covered by an arch, but left entirely open at the top. The apertures of the flues, F, and the chimneys, G, are then closed, as shown in Fig. 88, and the coal is ignited through the flues, E; the air then enters the flues, E, and passes through the coal, and then ascends the chimneys, H, as shown by the arrows. When the current of air has proceeded in this direction for some hours, the flues, E, and chimneys, H, are closed, and F and G are opened, which reverses the direction of the current of air through the mass. This alternation of the current is repeated as often as may be required. At the same time, air descends through the upper surface of the mass of coal. When the mass is well ignited, which takes place in from 24 to 36 hours, the external apertures of the flues, E and F, are closed, and the chimneys, G and H opened; the air now enters through the upper surface of the coal only, and descends through the mass of the coal, the products of combustion passing up the chimneys.

"The coking gradually ascends from the bottom of the mass to the top, and can be easily regulated or equalised by opening or closing, wholly or partially, the apertures of the flues or chimneys. The top surface of the coal being kept cool by the descending current of air, the workman is enabled to walk over it during the operation. He inserts, from time to time, at different parts of the surface an iron bar, which is easily pushed down until it reaches the mass of coke, by which its further descent is prevented. In this way the workman gauges the depth at which the coking process is taking place, and if he finds it to have progressed higher at one part than at another, he closes the chimneys communicating with that part, and thus retards the process there. This gauging of the surface is carried on without difficulty until the coking process has arrived close to the top. The gases and tarry vapours produced by the distillation or combustion, descend through the interstices of the incandescent mass below, and there deposit a portion of the carbon contained in them, the residual gases passing up the chimneys. The coke of the lower part of the kiln is effectually protected from the action of the air by being surrounded and enveloped in the gases and vapours which descend through it, and are non-supporters of combustion.

" When the mass of coal has been coked up to the top, which takes place in about seven days, it is quenched with water, the walls closing the end openings, *k*, are taken down, and the coke is taken away. When a portion has been removed, a movable railway is laid in the kiln, so as to facilitate the removal of the remainder of the coke.

" The flues, E and F, may enter at the bottom of the kiln, or at the sides above the bottom, as in Fig. 88. In the latter case, the space below, up to the level of the bottom of the flues, may be filled with small coal, which becomes coked by the radiated heat from the incandescent mass above. The transverse passages through the mass are then constructed upon this bed of small coal with the larger lumps, as before mentioned. The flues and chimneys need not necessarily be horizontal and vertical, and, instead of connecting a separate chimney with each transverse flue, flues may be constructed longitudinally in the walls of the kiln, so as to connect two or more of the transverse flues, which are then regulated by dampers conveying the gaseous products from them into chimneys of any convenient height; the arrangement first described, however, and shown in the drawings, is preferred. The gaseous products may be collected, and tar, ammonia, and other chemical compounds manufactured from them by the usual modes. The coking or charring of peat and wood may be effected in a similar manner to that already described with regard to coal.

" The new kilns have proved entirely successful; they are already in use in some of the largest iron works in the kingdom, and are being erected at a number of other works. The great saving in first cost of oven, economy in working and maintenance, increased yield, and improved quality of coke, will probably soon cause this mode of coking to be more generally introduced. The kilns are most advantageously made about 14 feet in width, 90 feet in length, and 7 feet 6 inches in height; this size of kiln contains about 150 tons of coal."

From the long experience of this gentleman, we are induced to quote yet furthur from his memoir:—

" The process of coking converts the coal into a porous mass, but this is done during the melting of the coal, at which moment the gases, in liberating themselves, form very minute bubbles; but the practical result is the same as in wood coal, allowing a large surface of carbon in a small space to be acted upon by the blast. As a general rule, coke made rapidly has larger pores, and is lighter than coke made slowly, it accordingly bears less blast, and crumbles too easily in the furnace.

" The process of coking in the ordinary ovens may be thus explained:—When the oven is filled with a proper charge, the coal is fired at the surface by the radiated heat from the roof, enough air is admitted to consume the gases given off by the coal, and thus a high temperature is maintained in the roof of the oven. The coal is by this means melted, and those portions of it which, under the influence of a high temperature, can of themselves form gaseous compounds, are now given off, forming at the moment of their liberation small bubbles or cells. The coke now left is quite safe from waste, unless a furthur supply of air is allowed to have access to it. At this stage of the process the coke assumes a pentagonal shape and columnar structure. When the coke is left exposed to heat for some time after it is formed, it becomes harder and works better, from being less liable to crush in the furnace and decrepitate on exposure to the blast. It has been often remarked as a strange fact, that the hotter the oven the better the yield of coke; hence all the arrangements of flues to keep up the temperature of the ovens. This fact is, however, the result of laws well known to chemists. When the coal is melted as above mentioned, the hydrogen in the coal takes up two atoms of carbon for each two atoms of hydrogen, forming bicarburetted hydrogen gas ($C_2H_2$); this at once escapes, but it has to pass upwards through the red-hot coke above, which is at a higher temperature than the melted coal below. Now when bicarburetted hydrogen gas is exposed to a bright red heat, it is decomposed, forming carburetted hydrogen gas ($CH_2$), and depositing one atom, or one-half of its carbon, in a solid form. Consequently, in the process of coking, if the oven is in good working order and the coke hot enough, the liberated carbon is detained in its passage upwards, and either absorbed by the coke, or crystallised *per se* upon it. This is simply illustrated by passing ordinary illuminating gas through a tube heated to a bright red heat. The tube will soon become coated internally, and ultimately filled with a carbonaceous deposit, produced by the decomposition of the bicarburetted hydrogen contained in the gas. It is found that some coal which is too dry, or not sufficiently bituminous to coke when put into the oven by itself in lumps, will coke perfectly if crushed small and well wetted with water, and charged in this state. This fact, if followed out, would lead to an examination of the chemical nature of the effect produced by the water, and would point the way to further improvements."

The "charred coal," which has been largely employed in lieu of charcoal in the manufacture of tin plates, is a species of coke. This preparation was first made by Mr. Ebenezer Rogers, who thus describes its manufacture:—

"The preparation of the 'charred coal' is very simple. The coal is first reduced to small, and washed by any of the ordinary means. It is then spread over the bottom of a reverberatory furnace to a depth of about 4 inches; the bottom of the furnace is first raised to a red heat. When the small coal is thrown over the bottom, a great volume of gases is given off, and much ebullition takes place. This ends in the production of a light spongy mass, which is turned over in the furnace, and drawn in about an hour and a half. To completely clear off the sulphur, water is now freely sprinkled over the mass, until all smell of the sulphuretted hydrogen gas produced ceases; the result is 'charred coal.' The quantities of charred coal hitherto produced have been made on the floor of an ordinary coke oven whilst red-hot, after drawing the charge of coke. The following analysis of the coal from which the 'charred coal' is made, is extracted from the report on the coals suited to the steam navy, by Sir H. de la Beche and Dr. Playfair:—

*Abercarn Coal.*

| | |
|---|---|
| Carbon . . . . . . . . . . . . . | 81·26 |
| Hydrogen . . . . . . . . . . . | 6·31 |
| Nitrogen. . . . . . . . . . . . | 0·77 |
| Oxygen . . . . . . . . . . . . | 9·96 |
| Sulphur . . . . . . . . . . . . | 1·86 |
| Ash . . . . . . . . . . . . . | 2·04 |

**Yield of Coke.**—According to Karsten,

| | Per Cent of Ash. | | Per Cent of Coke. |
|---|---|---|---|
| Sand coal, containing from | 1·60—29·0 | yields | 59—70 |
| Sinter coal ,, ,, | 0·60—23·0 | ,, | 58—78 |
| Caking coal ,, ,, | 0·15—27·7 | ,, | 51—86 |
| Anthracite ,, ,, | 0·60—20·0 | ,, | 72—96 |

Ovens yield from 8 to 10 per cent of coke less than heaps when calculating by volume, and the yield in both apparatus is nearly even when the weights are compared. Coke produced in ovens is more compact and harder than that resulting in heaps. When bituminous caking coal is coked in heaps the yield by volume may amount to from 110 to 120 per cent. Sinter coal modifies its volume but little, while sand coal sometimes loses 10 per cent in coking. The coke that results in heaps usually contains less sulphur than that produced in ovens; hues on the surface of the coke indicate the presence of a certain amount of sulphur.

Coke has generally an iron grey colour, a more or less porous appearance, and a silky or metallic lustre. On being touched, it does not soil the fingers. The coke produced from bituminous caking coal especially, has a metallic lustre, a fused appearance, and a blebby structure.

For the purpose of combustion, coke requires a strong red heat, and a lively draught.

Ebelmen,* Playfair, and Bunsen† have investigated the chemical reactions which take place in the process of coking.

**Composition of Coke.**—Coke contains on an average—

| | | |
|---|---|---|
| Carbon . . . . . . . | 85—92 | per cent |
| Ash . . . . . . . . | 3— 5 | ,, |
| Hygroscopic water . . | 5—10 | ,, |

The amount of ash in coke varies, however, between 1 and 30 per cent, and coke containing upwards of 12 per cent belongs to the more inferior kinds. The amount of hygroscopic water in coke sometimes increases to 20 per cent.

**Employment of Coke.**—Coke may be employed in all kinds of firing which do not require a large flame, but it is most effective in those instances in which great heat is required in a small space, as, for instance, in crucible meltings, in smelting of iron ores in blast furnaces, in re-melting of pig-iron in cupola furnaces, in the finery process, in the smelting of copper, lead, and silver ores, &c.‡

Soft caked coke is usually employed only in the lower kinds of blast furnaces,‖ as it does not offer sufficient resistance to the pressure which is exerted in higher furnaces by the column of ore.

When a sufficient quantity of air is admitted, coke produces a far greater heat than charcoal (page 337). As it remains longer in the furnace than charcoal, before being ignited, it undergoes a better preparatory heating before ignition, and by this means its effect is increased. Coke is also more effective than charcoal from the fact that it forms fewer interstices, which interstices diminish the quantity of carbon burnt in a certain space and time, and thus occasion a decrease of temperature.

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* B. u. h. Ztg., 1851, No. 29.

† Ibid., 1848, p. 5.

‡ Bgwkfd., i., 485; ii., 474, 475, 561, 572; iii., 153, 417; v., 445; viii., 523. KARST., Arch., xii., 531. KERL, Oberharzer Hüttenprocesse, 1860, p. 248. Jahrb. f. d. sächs. Berg-u. Hüttenmann, 1828, pp. 136, 151; 1831, p. 142; 1840, pp. 83, 88. Anwendung von Gascoke beim Eisenhohofenbetrieb, B. u. h. Ztg., 1860, pp. 212, 415.

‖ DINGL., cxxi., 97. Bgwkfd., v., 366. ERDM., J. f. pr. Ch., vi., 207.

**Heating Power of Coke.**—The following table shows the heating power of different kinds of coke, and the specific gravity of the porous mass filled with atmospheric air :—

| Kinds of Coke. | Per Cent of Hygroscopic Water. | Per Cent of Ash. | Heating Power. Absol. | Heating Power. Specific. | Heating Power. Pyrom. | Specific Gravity. |
|---|---|---|---|---|---|---|
| Good coke containing | 10 | 5 | 0·84 | — | 2350° | — |
| Best ,, ,, | 5 | 3 | 0·92 | — | 2400° | — |
| ,, ,, | without | 3 | 0·97 | — | 2450° | — |
| Sand coke | ,, | 5 | — | 0·46 | — | 0·48 |
| Sinter coke | ,, | 5 | — | 0·41 | — | 0·43 |
| Caked coke | ,, | 5 | — | 0·33 | — | 0·35 |

According to Berthier, French coke reduces from 22·2 to 28·5 parts of lead, and heats from 50·3 to 65·6 parts of water of 0° up to 100° C.

**Practical Results.**—Amongst others, the following practical results concerning the effect of coke, are obtained :—

1. Karsten states that, in blast furnaces carried on with hot blast,

100 parts in volume of coke are equal to 250 parts of charcoal,
100 lbs. ,, ,, 80 lbs. ,,

Including the interstices, the weight of 1 cubic foot (Prussian)—
of caked coke produced in ovens = 22—25 lbs. (Prussian)
,, ,, ,, heaps – 25—28 ,,
Sinter coke ,, ,, = 33 ,,
Sand coke ,, ,, = 35 ,,
,, ,, tar ovens = 38 ,,

2. The following results were obtained in the smelting works of the Lower Hartz :—

100 cubic feet of charcoal = 45 cubic feet of caked coke (Obernkirchen)
3 ,, gas coke = 3⅜ ,, ,, ,,
60 ,, wood = 7⅛ ,, ,, ,,
60 bundles of brush wood = 22⅛ ,, ,, ,,
10 cubic feet of pine nuts = 1½ ,, ,, ,,
10 ,, pine wood in billets = 54 lbs. of gas coke
10 ,, ,, (roots) = 72 ,, ,,
10 ,, ,, (branches) = 55 ,, ,,
10 ,, charcoal of beech wood = 96 ,, ,,

(The weights and measurements are Hanoverian).

3. The Society for Promoting Industry in Prussia has determined that 1 lb. of coke, which had been imperfectly

charred in heaps, containing from 5 to 6 per cent of water, and from 2·4 to 43 per cent of ash, converted from 7·15 to 7·58 lbs. of water of 0° into steam of 110—115° C. 1 ton (Prussian) = 7¼ cubic feet (Prussian) of this coke, weighs 251 lbs.

4. According to Fife,* mineral coal of Tarneut evaporates 5·66 times its own weight of water, and coke, produced from that coal, 7·4 times its own weight of water.

## II. GASEOUS FUEL.

The first attempts to employ combustible gases, and gas mixtures, instead of compact fuel, in technical operations, were made at the commencement of the present century; but it is only lately that the employment of gaseous fuel has been practically successful. We may say that every firing with raw fuel is a kind of gas firing, as the flame is produced by combustible gases; gas firing proper, is, however, understood to be that kind in which gases, either produced in special apparatus or collected as waste gases from other metallurgical processes, are burnt with a special admission of atmospheric air.

**Waste Gases.**—Thenard, Berthier, and Chevreul, made a report on the 28th of May, 1842, to the French Academy of Sciences, according to which, the waste gases of blast furnaces were first employed for the roasting of ores, burning lime, &c., during the years 1809 to 1811, by M. Aubertot,† who, in 1814, suggested that suitable furnaces should be constructed for the employment of the waste gases for metallurgical purposes. Lampadius had, in 1801, already proved the possibility of employing the waste gases escaping in the carbonisation of wood, and in 1830, at the smelting works near Freiberg, he attempted to cupel raw lead by means of gases produced from mineral coal.‡

According to a communication made by Ebelmen,‖ M. Victor Sire, of Clerval, obtained, in 1836, a patent for fifteen years, purporting the manufacture of wrought-iron by means of waste gases from blast furnaces. As M. Sire, however, found no means practically to employ his patent, the French laws obliged him to publish his patented mode of manufacture. According to a report of the Central Jury of the Paris Exhibition in 1844, Sire's patent was employed in 1838 at the iron works of Jägerthal, on the Lower Rhine, and since 1841 it has been in use at the iron works at Treveray, in the Department of the Moselle, in the fining of iron, but this mode of manufacture did not then obtain publicity.

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* Bgwkfd., vii., 222.

† Ann. d. min., 3 sér., xiii., 715.

‡ Erdm. J. f. pr. Ch., v., 206.

‖ Ann. d. min., 4 sér., tom. ii., 1812, p. 371.

Wilhelm von Faber du Faur, made successful experiments in 1837, at Wasseralfingen, in Würtemberg, to burn the waste gases of iron blast furnaces in a reverberatory furnace, and to employ them for the process of fining pig-iron.* This success created great attention, and it was generally acknowledged that this new mode of producing wrought-iron formed one of the most important progresses in the manufacture of iron, and it was consequently adopted by various iron works.

In the employment of the waste gases, it was, however, soon discovered that a modification in the process of the blast furnace modified the waste gases with regard to quality and quantity, in consequence of which the fining process became impaired. The collection of the gases also seemed to injure the process of the blast furnace.†

This dependence of the puddling furnace on the blast furnace, was so prejudicial, as to cause the method of fining by means of waste gases from blast furnaces, to be relinquished; on the other hand, the waste gases have found permanent employment in the roasting of ores, the heating of blast and boilers, the drying and carbonising of fuel, and the burning of lime and bricks, &c., processes in which a very high and uniform temperature is not required; a great deal of fuel was thus saved, and the collection of the waste gases also proved beneficial to the health of the workmen, and to the preservation of vegetation in the neighbourhood of the establishments.

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* Bgwkfd., iii., 497; iv., 380, 479; vi., 209, 225, 282.

† Ibid., xii., 785.

The utilisation of the waste gases has likewise been an inducement for the extensive employment of the new and very economical system of firing by means of gases which are artificially produced in a generator.

**Generator Gases.**—In the ordinary combustion of compact fuel on grates, a considerable loss of temperature, sometimes upwards of 60 per cent, takes place for the reasons stated on page 333, and for some purposes fuels of inferior kind cannot be burnt at all on the ordinary grates.

Before Faber's utilisation of the waste gases had obtained publicity, Bischof made experiments in the year 1839, in Mägdesprung, on the Hartz, the purpose of which was to produce gases of carburetted hydrogen, &c., by heating raw fuel in a furnace (generator), and to burn these gases by means of atmospheric air.* Gases thus produced from peat quickly yielded the highest welding heat. Bischof's results, however, were not made use of at once, as Faber's utilisation of the waste gases, which in the meantime had come under public notice, seemed to be more advantageous, for the reason that the waste gases do not require to be specially produced.

Austrian metallurgists who visited Wasseralfingen in 1838, and who considered that the employment of the waste gases in the puddling of iron would give no practical results, made the first attempts at the iron works in Jenbach, in Tyrol, in 1839 and 1840, to produce combustible gases by an imperfect combustion of small charcoal; dangerous explosions, however, again interrupted these experiments.†

Karsten‡ suggested, in 1841, that it was reasonably expected that those kinds of compact fuel which were not adapted for the puddling process, on account of their little heating power, and their state of aggregation, would soon be converted into carbonic oxide gas in special apparatus, and that this gas would accomplish the purpose in view.

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* BISCHOF, ii., die indirecte, aber höchste Nutzung der rohen Brennmaterialien, 2 Aufl., Quedlinburg, 1856, p. 6. B. u. h. Ztg., 1843, p. 55; 1855, p. 55.

† ZERRENNER's met. Gasfeuerung, p. 9.

‡ KARSTEN's Eisenhüttenkunde, Bd. iv., p. 271.

Heine* expressed a similar opinion in 1842.

Ebelmen, Thomas, and Laurens investigated in France, in 1841, the question of producing combustible gases in generators, and, at the same time, Frèrejean practically experimented on the subject at Crans, near Annecy, in Savoy.†

The experiments made at Jenbach, showed the practicability of firing with artificially produced gases, and proved its great effect. Further experiments were, therefore, made in 1842, at the steel works in St. Stephan, in Styria, to produce combustible gases from small brown coal, and again favourable results were obtained. These results were at once published,‡ and gave rise to the well-merited general introduction of the employment of artificially produced combustible gases.

This mode of firing has been further developed by Bischof, Thomas, Eck, and others, but especially by Mr. C. W. Siemens.

## A. Waste Gases.

Waste gases|| are generally understood to be those which are given off from the furnace head, but waste gases, properly speaking, are those which escape from any kind of furnace without being utilised.

The temperature which the waste gases on combustion may produce depends on the temperature of the gases, on their composition, and on the mode of burning them, that is to say, whether the burning is effected by hot or cold air (draught or blast). According to Faber du Faur, waste gases from iron blast furnaces, when burnt with hot blast, produce in puddling furnaces a temperature of 2700° C., and in re-heating

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* Bgwkfd., v., pp. 251, 252.

† Bulletin de la Société de l'industrie minér., tom. i., 245; ii., 449.

‡ Notizen über die unter der Oberleitung und nach Angaben des k. k. dirigirenden Bergraths und Oberbergamts-Directors Carl von Scheuchenstuel zu St. Stephan in Steyermark vorgenommenen Eisenfrischversuche mit alleiniger Benutzung des rohen Braunkohlenkleins. In TUNNER'S LEOB., Jahrb., ii. Jahrg., 1842, p. 257.

|| Zusammenstellung der Europäischen Literatur über Gichtgase und deren Benutzung von 1838—1855, in ZERRENNER'S met. Gasfeuerung, 1856, p. 250.

furnaces a temperature of 3100° C., but only when the gases are rich in carbonic oxide gas, nearly constant in composition, and at disposal in sufficient quantity. If a blast furnace is deprived of too many gases, as is the case now and then when they are required for various purposes, the operation of the furnace is impaired, in consequence of which the composition of the gases becomes modified, rendering them less adapted for employment as fuel.

The composition of the waste gases generally varies according to the nature of the fuel employed, the temperature and pressure of the air of combustion, the height at which the gases are collected from the furnace, and the state of the process. The waste gases are mixtures of combustible gases (carbonic oxide, hydrogen, carburetted hydrogen) and of non-combustible gases (carbonic acid and nitrogen). Hydrogen and carburetted hydrogen are produced either by dry distillation of the fuel, or by the action of the moisture entering the furnace, as, according to Bunsen,* the following mixture results when steam is conducted over red-hot coal:—

Hydrogen . . . 56·52 parts = 4 volumes.
Carbonic oxide gas 28·71 ,, = 2 ,,
Carbonic acid . . 14·77 ,, = 1 ,,

Nitrogen originates from the air of combustion.

Concerning the waste gases given off from iron blast furnaces, the following statements are contained in Ure's "Dictionary of Arts and Mines," vol. ii., p. 709:—

"The agent in blast furnaces by which the oxide of iron is reduced is carbonic oxide, the presence of which, therefore, in great excess is indispensable to the operation of the furnace. The flames rising from the tunnel head, which make a blast furnace at night such an imposing object, are occasioned principally by the combustion of this gas, on coming into contact with the oxygen of the atmosphere. The attention of practical men was first called to the enormous waste of heat which this useless flame entailed by Messrs. Bunsen and Playfair, and the application of the gas to a useful purpose may be ranked next to that of the heated blast, as the most important of the recent improvements in iron manufacture. The gases evolved from iron furnaces where coal is used as fuel contain the following constituents, viz., *nitrogen, ammonia, carbonic acid, carbonic oxide, light carburetted hydrogen, olefiant gas, carburetted hydrogen of unknown composition, hydrogen, sulphuretted hydrogen,* and *aqueous vapours.* The nature of the combustible gas stands in a relation so intimate to the changes suffered by the materials put into the furnace, that its different composition in the various regions of the furnace indicates the changes suffered by the materials introduced, as they descend in their way to the entrance of the blast. Now, as the examination of this column of air in its various heights in the furnace, must be the key to the questions upon which the theory and practice of the manufacture of iron depend, it was of the first importance to subject it to a rigid examination. This, accordingly, has been done by the above-named eminent chemists, and subsequently by Ebelmen. We shall presently return to a consideration of the results they obtained, confining our attention at present to the composition of the gases at the mouth of the furnace.

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* Liebig's Ann. d. Chem. u. Pharm., lxxxv., 150.

"In order to arrive at a knowledge of the composition of these gases, M. Bunsen first studied minutely the phenomena which would ensue were the furnace filled with fuel only, by a careful distillation of a known weight of coal, and by analysing the products, he obtained results embodied in the subjoined table:—

| | |
|---|---|
| Carbon | 68·925 |
| Tar | 12·230 |
| Water | 7·569 |
| Light carburetted hydrogen | 7·021 |
| Carbonic oxide | 1·135 |
| Carbonic acid | 1·073 |
| Condensed hydrocarbons and olefiant gas | 0·753 |
| Sulphuretted hydrogen | 0·549 |
| Hydrogen | 0·499 |
| Ammonia | 0·211 |
| Nitrogen | 0·035 |
| | 100·000 |

"Now, in the furnace the oxygen introduced by the blast is consumed in the immediate vicinity of the tuyere, being there converted into carbonic oxide, and the coal loses all its gaseous products of distillation much above the point at which its combustion commences, near, in fact, to the top of the furnace. The fuel with which the blast comes into contact is, therefore, coke, and upon calculating the amount of carbonic oxide produced by the combustion of 68·925 per cent of carbon, and the nitrogen of the air expended in the combustion, we get at the composition by volume of the gases escaping from a furnace filled with Gasforth coal; it is as follows:—

| | |
|---|---|
| Nitrogen | 62·423 |
| Carbonic oxide | 33·163 |
| Light carburetted hydrogen | 2·527 |
| Carbonic acid | 0·139 |
| Condensed hydrocarbon | 0·151 |
| Sulphuretted hydrogen | 0·091 |
| Hydrogen | 1·431 |
| Ammonia | 0·070 |
| | 100·000 |

With this preliminary information, Bunsen proceeded to calculate the modification of the gaseous mixture occasioned by the introduction into the furnace of iron ore and limestone. The materials used for the production of 140 lbs. of pig-iron were—

420 lbs. of calcined iron ore, 390 lbs. of coal, 170 lbs. of limestone. From 100 parts of coal 67·228 parts of coke were obtained; but from this must be deducted 2·68 ashes and 1·18 carbon entering into combination with the iron, which leaves as the quantity of carbon actually burnt into carbonic oxide before the tuyere 63·368. Part of this carbonic oxide undergoes oxidation into carbonic acid at the expense of the oxygen in the oxide of iron, which it reduces. A further quantity of carbonic acid is derived from the limestone; so that the gases returned to the mouth of the furnace by the combustion of the 67·228 parts of coke, the reduction of the corresponding quantity of ore, and the decomposition of limestone consist of—

| | |
|---|---|
| Nitrogen | 282·860 |
| Carbonic acid | 59·482 |
| Carbonic oxide | 121·906 |
| | 464·248 |

Add to this the products of the distillation of the coal, and we get the following as the percentage compositions, by weight and measure, of the gases issuing from the mouth of the furnace:—

| | By Weight. | By Volume. |
|---|---|---|
| Nitrogen | 59·559 | 60·907 |
| Carbonic acid | 12·765 | 8·370 |
| Carbonic oxide | 26·006 | 26·846 |
| Light carburetted hydrogen | 1·397 | 2·536 |
| Hydrogen | 0·078 | 1·126 |
| Condensed hydrocarbon | 0·108 | 0·112 |
| Sulphuretted hydrogen | 0·053 | 0·045 |
| Ammonia | 0·054 | 0·058 |
| | 100·000 | 100·000 |

The calculations of the quantity of heat capable of being realised in the furnace by the combustion of the furnace gases, are founded on the data on the heat of combustion, given in the posthumous papers of Dulong, according to which 1 kilogramme or 15,434 grains of

| | | | | °C. |
|---|---|---|---|---|
| Carbon burning to CO | heats 15,434 | grains of water | to | 1499 |
| ,, ,, $CO_2$ | ,, | ,, | ,, | 7371 |
| Carbonic oxide | ,, | ,, | ,, | 2502 |
| Hydrogen | ,, | ,, | ,, | 34706 |
| Light carburetted hydrogen | ,, | ,, | ,, | 13469 |
| Olefiant gas | ,, | ,, | ,, | 12322 |
| Sulphuretted hydrogen | ,, | ,, | ,, | 4476 |
| Ammonia | ,, | ,, | ,, | 6060 |

Using these numbers, it is found that by the combustion of 100 of the furnace gases there are generated from the

| | | |
|---|---|---|
| 59·559 | Nitrogen | — |
| 12·765 | Carbonic acid | — |
| 26·006 | Carbonic oxide | 65067 |
| 1·397 | Carburetted hydrogen | 18826 |
| 0·078 | Hydrogen | 2704 |
| 0·108 | Olefiant gas | 1331 |
| 0·053 | Sulphuretted hydrogen | 238 |
| 0·034 | Ammonia | 208 |
| | | 88374 = |

units of heat, the *unit* being understood to mean the amount of heat necessary to raise one kilogramme = 2·204 lbs. = 15,434 grains of water from 0° C. to 1° C. The amount of heat *realised* in the furnace is limited to that produced by the expenditure of the oxygen, corresponding to 59·559 nitrogen in the production of carbonic oxide. This amounts to 2001 units; hence follows the remarkable conclusion that, in the furnace which was the subject of experiment, not less than 81·54 per cent of the fuel is lost in the form of combustible matter still fit for use, and that only 18·46 per cent of the whole fuel is realised in carrying out the processes in the furnace.

"The temperature which should be produced by the flame of the furnace gases, when burnt with air, is found by dividing the units of heat, viz., 883·74 arising from the combustion of one kilogramme of the gases, by the number resulting when the quantity of the products of combustion is multiplied by their specific heat (1·9338 × 0·2696). We thus get the number 3083° Fahr.; but this is below the truth, inasmuch as there is an accession of combustible gases at the mouth of the furnace, arising from the decomposition of the liquid products of the distillation of the coal in its passage over the red-hot fuel. Making proper allowance for this, and using numbers derived from actual experiments, Messrs. Bunsen and Playfair calculated the temperature of the gases, when generated under favourable conditions, at 3214° F., and even this may be increased to 3632° F., a temperature far above that of cast-iron, by the use of a blast sufficiently heated."

Analyses of gases from a furnace at Alfreton, in Derbyshire, at various depths below the surface, gave to Messrs. Bunsen and Playfair the results embodied in the subjoined table. The furnace was supplied with eighty charges in the course of twenty-four hours, each charge consisting of 390 lbs. of coal, 420 lbs. of calcined ironstone, and 170 lbs. of limestone, the product being 140 lbs. of pig-iron. The gases were collected through a system of tubes of malleable iron, 1 inch in diameter, and were received in glass tubes 4 inches long, and ¾ of an inch in diameter. The well-known skill of M. Bunsen as a gas analyst is a guarantee for the accuracy of the determinations:—

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* URE's Dictionary of Arts and Mines, vol. ii., p. 716.

*Composition of the Gases taken from different Depths in the Furnace.*

| | I.<br>5 ft. | II.<br>8 ft. | III.<br>11 ft. | IV.<br>14 ft. | V.<br>17 ft. |
|---|---|---|---|---|---|
| Nitrogen . . . | 55·35 | 54·77 | 52·57 | 50·50 | 55·49 |
| Carbonic acid . . | 7·77 | 9·42 | 9·41 | 9·10 | 12·43 |
| Carbonic oxide. . | 25·97 | 20·24 | 23·16 | 19·30 | 18·77 |
| Light carburetted hydrogen. . . | 3·75 | 8·23 | 4·57 | 6·64 | 4·31 |
| Hydrogen . . . | 6·73 | 6·49 | 9·33 | 12·42 | 7·62 |
| Olefiant gas. . . | 0·43 | 0·85 | 0·95 | 1·57 | 1·38 |
| Cyanogen . . . | — | — | — | — | — |

| | VI.<br>20 ft. | VII.<br>23 ft. | VIII.<br>24 ft. | IX.<br>34 ft. |
|---|---|---|---|---|
| Nitrogen . . . | 60·46 | 58·28 | 56·75 | 58·05 |
| Carbonic acid . . | 10·83 | 8·19 | 10·08 | — |
| Carbonic oxide . . | 19·43 | 29·97 | 25·19 | 37·43 |
| Light carburetted hydrogen . . . | 4·40 | 1·64 | 2·33 | — |
| Hydrogen. . . . | 4·83 | 4·92 | 5·65 | 3·18 |
| Olefiant gas . . . | — | — | — | — |
| Cyanogen. . . . | — | trace | trace | 1·34 |

From these analyses it appears:—

1. That at a depth of 34 feet from the top, within 2 feet 9 inches of the tuyere, the gas was entirely free from carbonic acid, but contained an appreciable quantity of cyanogen.

2. That the nitrogen is at a minimum at 14 feet.

3. That carburetted hydrogen is found as low as 24 feet, indicating that, at that depth, coal must be undergoing the process of coking.

4. That hydrogen and olefiant gases are at a maximum at 14 feet.

5. That the proportions between the carbonic acid and carbonic oxide are irregular, which is probably to be explained

by the fact that water is decomposed as its vapour passes through the layers of hot coal.

The average composition of the gases evolved from the materials used in the blast furnace, is somewhere between the following numbers:—

| | | |
|---|---|---|
| Nitrogen . . . . . . . . | 60·907 | 57·878 |
| Carbonic acid . . . . . | 8·370 | 9·823 |
| Carbonic oxide . . . . . | 26·846 | 24·042 |
| Light carburetted hydrogen | 2·536 | 2·743 |
| Hydrogen . . . . . . . | 1·126 | 4·972 |
| Olefiant gas . . . . . . | 0·112 | 0·392 |
| Sulphuretted hydrogen . . | 0·045 | 0·035 |
| Ammonia . . . . . . . | 0·058 | 0·115 |
| | 100·000 | 100·000 |

The proportion of nitrogen to oxygen, as an average deduced from these analyses, is 79·2 to 27. The product of the combustion of coal gives the same proportions as those existing in atmospheric air, viz., 79·2 : 20·08. The excess of oxygen must therefore depend upon the carbonic acid of the limestone, and the oxygen of the ore given to carbon during the process of reduction. Now, as at a depth of 24 feet the gas collected contained 27·6 and 26·5 oxygen to 79·2 nitrogen, it is held that at this depth the gas must already have abstracted all the oxygen of the ore and the carbonic acid of the limestone; and the conclusion is drawn that in hot blast furnaces fed with coal, the reduction of the iron and the expulsion of the carbonic acid from the limestone, takes places in the boshes of the furnace. The region of reduction in a furnace smelting with coal, must be much lower than when the fuel is coke or charcoal, because a large portion of the body of the furnace must be taken up in the process of coking, and the temperature is thereby so depressed that it is neither sufficient for the reduction of the ore, nor for the expulsion of carbonic acid from the limestone.

The mean general results obtained by Ebelmen from a charcoal furnace at Clerval, are the following. The methods of analysis adopted by this chemist were altogether different from those employed by Bunsen and Playfair:—

| No. of Analysis | I. | II. | III. | |
|---|---|---|---|---|
| Depth below mouth | 3 ft. 3 in. | 3 ft. 3 in. | 9 ft. 9 in. | 9 ft. 9 in. |
| Carbonic acid | 12·01 | 11·95 | 4·14 | 4·23 |
| Carbonic oxide | 24·65 | 23·85 | 31·56 | 31·34 |
| Hydrogen | 5·19 | 4·31 | 3·04 | 2·77 |
| Carburetted hydrogen. | 0·93 | 1·33 | 0·34 | 0·77 |
| Nitrogen | 57·22 | 58·56 | 60·92 | 60·89 |
| Total | 100·00 | 100·00 | 100·00 | 100·00 |
| Oxygen per 100 nitrogen. | 42·50 | 40·80 | 32·70 | 32·70 |
| Carbon vapour per 100 nitrogen | 32·80 | 31·70 | 29·60 | 29·60 |

| No. of Analysis | IV. | V. | VI. | VII. |
|---|---|---|---|---|
| Depth below mouth | 19 ft. 6 in. | 19 ft. 6 in. | 27 ft. | Tymp. |
| Carbonic acid | 0·49 | 0·07 | — | 0·93 |
| Carbonic oxide | 35·05 | 35·47 | 37·55 | 39·86 |
| Hydrogen. | 1·06 | 1·09 | 1·13 | 0·79 |
| Carburetted hydrogen | 0·36 | 0·31 | 0·10 | 0·25 |
| Nitrogen | 63·04 | 63·06 | 61·22 | 58·17 |
| Total | 100·00 | 100·00 | 100·00 | 100·00 |
| Oxygen per 100 nitrogen. | 28·50 | 28·20 | 30·70 | 35·80 |
| Carbon vapour per 100 nitrogen | 28·50 | 28·50 | 30·70 | 35·90 |

1. Gas taken a short time after the introduction of the charge. 2. The same taken a quarter of an hour after charging. 3. Gas collected through a cast-iron tube 4 inches in diameter; it rushed out with a noise and gave a sheet of flame, carrying with it particles of charcoal and dust. 4. Gas collected by boring the masonry; it rushed out violently, burning with a blue-coloured flame. 5. The same taken an hour after. 6. Gas collected by boring the masonry at the back of the furnace, about 3½ feet above the tuyere; it burnt with a white flame, giving off fumes of oxide of zinc; it was collected through porcelain tubes. 7. Gas collected through gun barrels, lined with porcelain; it was evolved with sufficient force to project scoriæ and even cast-iron.

The furnace was working with cold blast under a pressure of 0·44 inch of mercury. The charges had the following composition :—Charcoal, 253 lbs.; minerals (various), 397 lbs.; limestone, 254 lbs. Thirty-two charges were driven in twenty-four hours; the furnace was stopped after every twenty charges; the produce was 3970 lbs. of grey cast-iron ; the daily yield being about 6175 lbs.

The experiments show that while the carbonic acid progressively diminishes downwards, the carbonic oxide progressively increases, the former disappearing altogether at a depth of 27 feet. On examining the numbers representing the oxygen and carbon referred to 100 nitrogen, it is seen that they diminish progressively to a depth of 19 feet, the oxygen combined varying from 42·5 to 28·2. The proportion of carbon in the same zone rises from 28·5 to 32·8, a result brought about as much by the carbonic acid disengaged from the minerals, as from the gaseous products of the distillation of the charcoal. It is seen that the reduction of the mineral is already considerably advanced at the depth of 19½ feet, and this, so to speak, without any consumption of charcoal, but through the conversion of carbonic acid into carbonic oxide. The hydrogen decreases as the carbonic oxide increases, showing that this gas exercises no influence in the reduction of the ore.

The results obtained by M. Ebelmen, from a coke furnace at Seraing, were as under:—

| No. of Experiment | I. | | II. | III. |
|---|---|---|---|---|
| Depth | 1 ft. | 1 ft. | 4 ft. | 9 ft. |
| Carbonic acid | 11·39 | 11·39 | 9·85 | 1·54 |
| Carbonic oxide | 28·61 | 28·93 | 28·06 | 33·88 |
| Hydrogen | 2·71 | 3·04 | 0·97 | 0·69 |
| Carburetted hydrogen | 0·20 | — | 1·48 | 1·43 |
| Nitrogen | 57·06 | 56·64 | 59·64 | 62·46 |
| Totals | 100·00 | 100·00 | 100·00 | 100·00 |
| Oxygen per 100 nitrogen | 45·00 | 45·60 | 40·00 | 29·60 |
| Carbon vapour per 100 nitrogen | 35·20 | 35·70 | 33·00 | 29·40 |

| No. of Experiment | IV. | | V. | VI. |
|---|---|---|---|---|
| Depth | 10 ft. | 10 ft. | 12 ft. | 45 ft. |
| Carbonic acid | 1·08 | 1·13 | 0·10 | — |
| Carbonic oxide | 35·20 | 35·35 | 36·30 | 45·05 |
| Hydrogen | 1·72 | 2·08 | 2·01 | 0·25 |
| Carburetted hydrogen | 0·33 | 0·29 | 0·25 | 0·07 |
| Nitrogen | 61·67 | 61·15 | 61·34 | 54·63 |
| Totals | 100·00 | 100·00 | 100·00 | 100·00 |
| Oxygen per 100 nitrogen | 30·20 | 30·60 | 29·90 | 41·20 |
| Carbon vapour per 100 nitrogen | 29·60 | 30·00 | 29·90 | 41·30 |

1. Gas obtained by plunging an iron tube, 3 centimetres in diameter, about 1 foot into the furnace. 2. The same; the gas burnt spontaneously. 4. Two consecutive analyses of the same gas. 5. The gas was collected by an iron tube. 6. Gas collected by piercing the masonry 2 feet above the tuyeres; the gas was accompanied by fumes of cyanide of potassium, but no cyanogen could be detected.

The furnace was 50 feet high; the air was supplied through two tuyeres, and was heated to 212° C.; it was driven at the rate of 26,840 gallons per minute, under a pressure of 0·5 of mercury. The charges were composed of unroasted minerals, 1434 lbs.; forge cinders, 1434 lbs.; limestone, 948 lbs.; coke, 1765 lbs. The metal was run every twelve hours, and 17,500 lbs. of white crystalline cast-iron obtained, which was run in thin plates, and taken directly to the puddling furnace. The yield of the mineral was 42 per cent, and the consumption of coke 1500 per 1000 of cast-iron, rising from 1800 to 2000 per 1000 of iron when the furnace was working for foundry iron.

The proportion of carbonic acid in the gases obtained from different heights in a furnace,* has been studied by MM. E. Montefiore Levi and Dr. Emil Schmidt (Zeitschrift des Oesterr. Ingenieurvereins, 1852). They found that the zone from which this gas is entirely absent is of very limited extent, for although it is not met with at a height of 8 feet from the tuyere, it exists at 9 feet to the extent of 4·78 per cent, above which point it diminishes up to 15 feet, where it is *zero*. From this point it again increases, amounting to a height of 30 feet to 3·5 per cent. It then gradually diminishes, until, at a point from 37 to 39 feet above the tuyere, it amounts only to 1·69 or 1·91 per cent, after which it goes on increasing with rapidity and regularity up to the furnace mouth. The carbonic acid existing in the furnace gases, between 15 and 30 feet, is referred by these chemists to the decomposition of the limestone used as a flux; and its gradual diminution above this point indicates a reaction of considerable importance, namely, that of the carbonic acid upon the ignited coke, carbon being taken up, and carbonic oxide formed. Now, the quantity of carbon taken up by 275 parts of carbonic acid to convert it into carbonic oxide amounts to 75 parts, and as, in the furnace experimented with, 20,000 kilogrammes of limestone, containing about 8000 kilogrammes of carbonic acid, were consumed every twenty-four hours, a loss of fuel, equivalent to 2173 kilogrammes of carbon, was daily occasioned by the conversion of this carbonic acid into carbonic oxide, and this may be considered equivalent to 2500 kilogrammes of coke with 11 per cent of ash. The heat absorbed by the conversion of the carbonic acid of the limestone into a gaseous state is found by calculation, taking the specific heat of carbonic acid as 0·22, and the heating power of coke at 6000, to be equivalent to that developed by the combustion of 322 kilogrammes of coke. Now, it was demonstrated by Dulong, that the quantity of heat disengaged in the conversion of carbon into carbonic oxide is much *less* than that disengaged in the conversion of carbonic oxide into carbonic acid, although the same quantity of oxygen is required in both cases. The conversion of carbonic acid into carbonic oxide, by passing over ignited carbon, is essentially a two-fold action—a combination of carbon with oxygen, and a decomposition of carbonic acid into carbonic oxide and oxygen—the former is accompanied by development, the latter by absorption, of heat; the latter preponderates to such an extent as to indicate a loss of temperature equivalent to the heat developed by the combustion of 1609 kilogrammes of coke.

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* Ure's Dictionary of Arts and Mines, vol. ii., p. 720.

The authors were led by these observations to employ burnt lime in working blast furnaces, and thus obviate the loss of heat (vol. ii., page 406).

According to Scheerer, the waste gases have sometimes the following composition, and may possess the subjoined heating powers :—

| | Gases from | | | |
|---|---|---|---|---|
| | Charcoal. | | Coke. | Mineral Coal. |
| | I. | II. | | |
| Nitrogen. . . . . . . . . | 63·4 | 59·7 | 64·4 | 56·3 |
| Carbonic oxide . . . . . | 29·6 | 20·2 | 34·6 | 21·5 |
| Carbonic acid . . . . . . | 5·9 | 19·4 | 0·9 | 15·2 |
| Light carburetted hydrogen . | 1·0 | 0·3 | — | 4·2 |
| Hydrogen . . . . . . . . | 0·1 | 0·4 | 0·1 | 1·0 |
| Olefiant gas . . . . . . | — | — | — | — |
| Total. | 100·0 | 100·0 | 100·0 | 100·0 |
| Absolute heating power . . | 0·081 | 0·06 | 0·077 | 0·162 |
| Specific „ „ | 0·000105 | 0·000078 | 0·0001 | 0·000211 |
| Pyrometric „ „ | 1255° C. | 1075° C. | 1265° C. | 1480° C. |

For further details we refer to the following investigations :—

A. **Gases from Iron Blast Furnaces.**

1. Charcoal furnaces.
    - *a.* At Veckerhagen, investigated by Bunsen (Pogg. Ann., xl., 193).
    - *b.* At Clerval, by Ebelmen (Ann. d. min., 3 sér., xx., 359).
    - *c.* At Bärum in Norway, by Scheerer and Langberg (Pogg. Ann., lx., 489. Bgwkfd., vii., 289 ; ix., 189).
    - *d.* At Eisenerz, by R. Richter (Tunner's Leob. Jahrb., Bd. ix., 1860, p. 313).
2. Furnaces carried on with a mixture of charcoal and air-dried wood at Audincourt, by Ebelmen (Ann. d. min., 3 sér., xx., 359).
3. Coke furnace at Vienne and Pont l'Evêque (Ann. d. min., 4 sér., v., 3).
4. Furnace at Alfreton, carried on with mineral coal, by Bunsen and Playfair (Erdm., J. f. pr. Ch., xlii.,

145. Berzelius, Jahresber., 1848, pp. 54, 199. Bgwkfd., xii., 369).

B. **Waste Gases from Finery Fires**, carried on with charcoal at Audincourt, by Ebelmen (Ann. d. min., 4 sér., iii., 167).

C. **Waste Gases from Copper, Lead, and Silver Smelting Furnaces.**

1. From the furnaces at Mansfeld for melting copper schist.
    - *a.* Smelting with charcoal, by Bunsen (Pogg. Ann., l., 81. Bgwkfd., iii., 257; v., 209; vi., 513).
    - *b.* Smelting with coke; the same.
    - *c.* Smelting with coke and charcoal; the same.
    - *d.* Smelting with coke and coal (Bgwkfd., vii., 545).
    - *e.* Smelting with wood.
2. From copper smelting furnaces in Russia, by Schubin (B. u. h. *Z*tg., 1846, p. 569).
3. From furnaces for smelting raw matt with coke in Freiberg, by Karsten (B. u. h. *Z*tg., iii., p. 137).

**Employment of the Waste Gases.**—The employment of waste gases for metallurgical and other technical purposes is very variable; they are used, for instance, as follows:—

1. Waste gases from iron blast furnaces[*] are employed in puddling iron, roasting iron ores, heating the blast, drying and charring wood, burning bricks and lime, heating boilers, in the manufacture of cement steel, &c.

2. The waste gases from cupola furnaces[†] are used for heating the blast, boilers, &c.

3. The waste gases from finery fires[‡] are employed for heating the blast, for the preparatory heating of the pig-iron

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[*] Bgwkfd., iii., 479; iv., 156, 267, 302, 304, 479; vi., 209, 225, 282, 319; vii., 94, 465; viii., 198, 222; ix., 465; x., 104, 121; xi., 469; xii., 7; xiii., 517. DINGL., cxxvii., 116, 261; lxxxix., 119. POGG. Ann., l., 81, 637. ERDM., J. f. pr. Chem., xxii., 389; xxvi, 248, 231. B. u. h. Ztg., ix., 353, 369, 673; xi., 579; xiv., 153; xv., 90; xvii., 119, 234; xix., 131, 148, 313.

[†] Bgwkfd., xi., 125. Polyt. Centr., 1847, p. 917. B. u. h. Ztg., 1842, p. 261; 1855, p. 177.

[‡] ERDM., J. f. ök. u. techn. Chem., vii., 137. Bgwkfd., iv., 449; v., 89, 169, 850; vi., 296; ix., 513: xi., 97; xii., 462; xiii., 641. Polyt. Centr., 1850, p. 428. DINGL., cxxx., 30. B. u. h. Ztg., 1854, p. 12; v., 89, 169, 850.

to be fined, for re-heating the blooms, for the puddling process, for drying wood, &c.

4. The waste flame from a copper smelting furnace* in Russia, is used for refining black copper in a reverberatory furnace.

The waste gases from the copper smelting furnaces at Mansfeld and Riechelsdorf† have less combustibility than those from iron blast furnaces, and their employment is, therefore, less advantageous.

5. The waste gases from lead smelting furnaces. Rieneckert‡ has made use of the flame containing oxide of lead, escaping at the cupelling process, for burning and glazing bricks. The employment of the waste gases from lead furnaces at Kremnitz,‖ for roasting lead and silver ores in the form of *schlich*, has not been successful, for the reason that the result of the roasting process depended on the regularity of the furnace process, and the roasted mass acquired a pulverulent and not a compact consistency. Attempts have been made to use the waste gases from the lead smelting furnaces at the Upper Hartz,§ for roasting lead matt, but likewise without success.

**Collecting the Waste Gases.**—Various methods are employed for collecting the gases (vol. ii., page 447). The best apparatus used in this country seems to be that adopted at Ebbw Vale, Sirhowy, and Cwm Celyn, of which we gave a small sketch in vol. ii., Fig. 108, and which is here represented by Figs. 89, 90, 91, 92, 93, and 94. These Figs. were furnished for Ure's "Dictionary" by the proprietor of the Cwm Celyn and Blaina Iron Works.

Fig. 95 shows the plan which is adopted at the Brymbo Iron Works, near Wrexham, for extracting the gases; it is the patent of C. E. Darby. It consists of a large pipe or tube inserted into the middle of the top part of the furnace, which descends a short distance down into the materials, and is carried over the top of the side of the furnace in the form of a syphon, a continuation of which pipe is taken to the boilers or hot air

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* B. u. h. Ztg., v., 569.

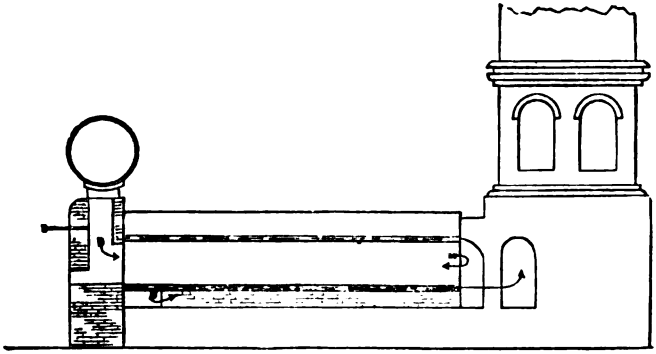
† Ann. d. Min., 4 sér., iv., 541.

‡ Bgwkfd., xi., 617.

‖ Oesterr. Ztschr., 1856, p. 60.

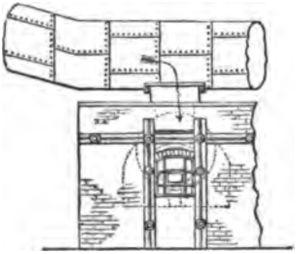
§ Kerl, Oberh. Hüttenpr., 2 Aufl., 1864, p. 234.

FIG. 89.



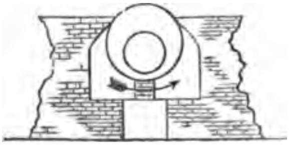
stoves, where the gas is burnt in the usual way. The principal advantage claimed by this method is, that it puts

FIG. 90.



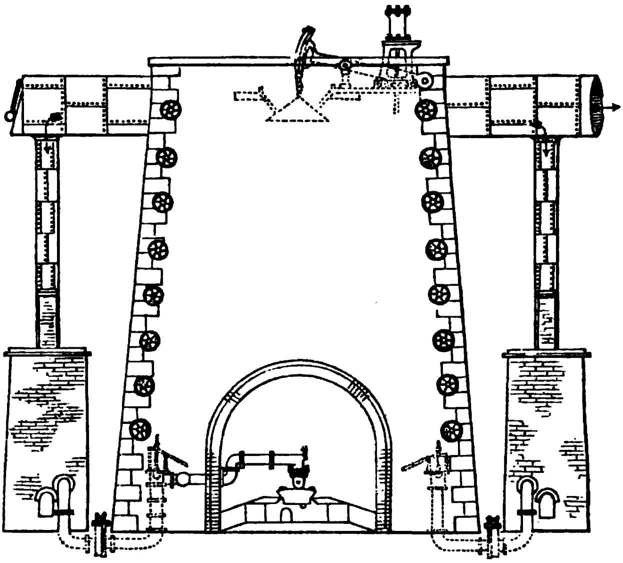
no check on the free escape of the gases, by which the driving of the furnace is impeded, and the quality of the iron de-

FIG 91.



terioriated. The patentee estimates the saving of fuel with two furnaces making 240 tons of iron per week, by applying the gas to the blast engine, boilers, and hot air stoves, at £1200 a year. Thus :—Consumption of fuel at engine and stoves, equal to 7 cwts. of good coal per ton of iron, made

FIG 92.



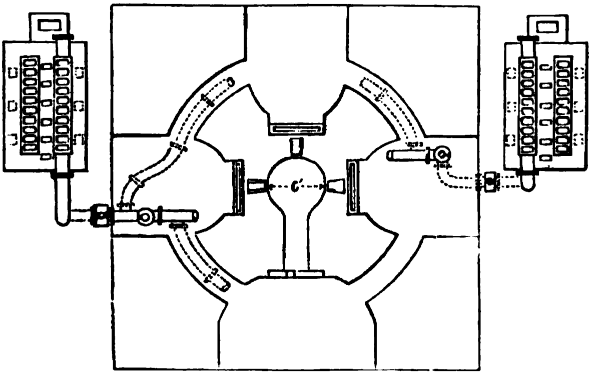


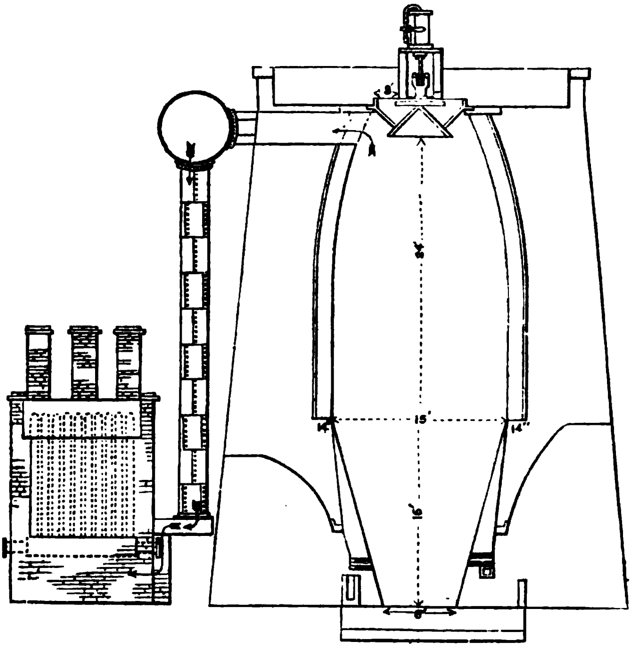
FIG. 93.

at 3½ per cwt., is 2s. 0½d., say 2s. per ton on 12,480 tons, or £1248.

The causes of derangement in the working of blast furnaces when the gases are drawn off to be utilised elsewhere, have been diligently studied by Mr. George Parry, of Ebbw Vale, and are described by him in Ure's "Dictionary of Arts and Mines," vol. ii., p. 712, thus :—

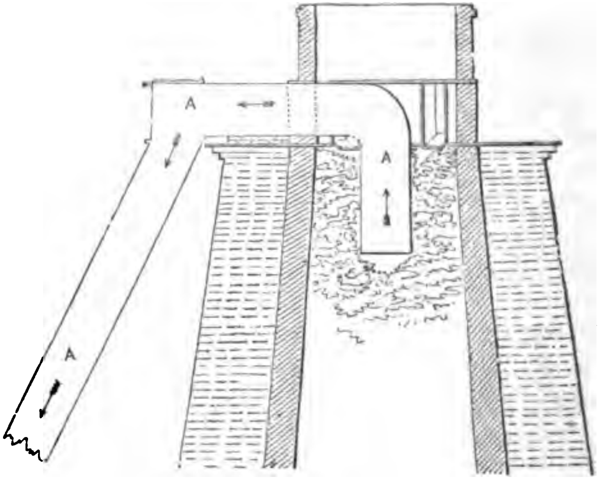
"The manner in which the waste gases were formerly collected, was by sinking an iron tube, 7 feet deep, into the throat of the furnace, the diameter of the tube being about 3 feet less than that of the throat, thus leaving an annular space of 18 inches between the walls of the furnace and the sides of the tube. From this space, the gases were allowed to pass off by the pressure within the furnace, through a pipe which penetrated the ring and walls. When the tube was kept full of minerals, about one-third or a quarter only of the gas escaped into the open air, the rest passing into the annular chamber, and when this state of things was continued, those troublesome adhesions of masses of semi-fused materials above and around the boshes, technically termed 'scaffolds,' occurred, with the usual accompaniment

FIG. 94.



of black cinder and inferior iron. It is evident that when the tube was kept full of minerals, the contents acted as a loose stopper to the current of hot gases, forced up by pressure from beneath, and diverted them towards the annular space, where there was no such resistance, thus leaving the minerals in the central parts of the furnace insufficiently supplied with the upward current, and consequently with heat; the minerals, on the other hand, surrounding the cold central cone, were supplied with more than their usual quantity of heat, as was evidenced by the

Fig. 95.

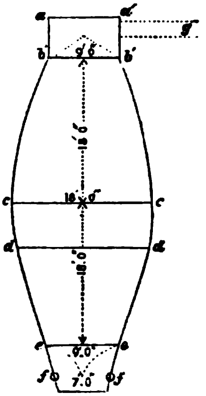


burning of tuyeres, and by the destruction of the brickwork in their neighbourhood. In this state of things, the ores in the external portions of the furnace would become reduced and converted into grey metal, while those in the central portions would, according to the degree of deviation of the ascending current of heated gases from them, descend to the point of fusion either thoroughly deoxidised and slightly carbonised, or possibly with a portion still in the state of oxide, and mixing there with the properly reduced ores, enter into fusion with them, producing a mixture of irons which must necessarily prove of inferior quality, and a black cinder from the unreduced oxides. When the iron tube in the throat of the furnace was only partially filled with materials, much more gas escaped into the open air, as might have been expected, and consequently more traversed the central parts of the furnace; and it was always observed that when that mode of filling was adopted, the furnace worked much better; but then the object, *viz.*, that of economising the gases, was not attained. Differently formed furnaces were found to be disturbed in different degrees by this system of drawing off the gases; the old conical *narrow* topped furnaces were affected very much less than the improved modern *domed* top furnace of large capacity, from which all attempts to take off any useful portion of the gases proved absolute ruin. It might be argued that, as the same quantity of blast and fuel were used as heretofore, the ascending current of heated gases ought to produce the same deoxidising and carbonising effect on the superincumbent mass, whatever direction they might take in making their escape in the upper region of the furnace; for if the central part should not have been sufficiently acted upon, the external annulus would have more than its usual share of chemical influences. But when it is considered that iron is only capable of taking up a certain quantity of carbon, and no more, it follows that, after having received this amount, its further exposure in the external parts of the furnace where the heated gases abound, can do nothing towards supplying the sufficiency of carbon in the metal reduced in the central part. From these considerations it became evident that no system of drawing off the gases around the sides, whether by the insertion of an iron tube into the throat, or by lateral openings through the walls into a chamber surrounding the top of the furnace, can be adopted without more or less injury to its action, and that the only unobjectionable mode would be to take the gases from a chamber above the minerals, thus equalising the pressure on the whole sectional area of the mouth, and thereby allowing an equally free flow for the ascending current up the middle, as well as up the sides of the furnace. By this method, the whole of the waste gases would become utilised, instead of a portion only, and the furnace would be restored to its original state, inasmuch as the direction of the flow of heated gases would not be interfered with by unequal resistance. To form this chamber, the furnace must be covered in, and fed through a hopper, a plan long adopted at the Codner Park Iron Works, with the supposed advantage of scattering the minerals around the sides of the furnace, and preventing their accumulating in the centre; a conical charger of this description, but fixed in the throat of the blast furnace, was in use in the Cyfarthfa Works more than half a century ago, the minerals being thrown by baskets to the centre of the cone, and allowed to roll down to the sides of the furnace, thus giving a cup form to the surface of the minerals, the larger lumps, of course, rolling to the centre, and affording a freer passage in that direction for the upward current. It was not, however, until January, 1851, that a trial was made at the Ebbw Iron Works, of an apparatus of this description for collecting the gases. It was then supplied to one of the old forms of conical furnace with a narrow top, and the trial proved eminently successful, the furnace producing any quantity ot iron required, according to the burden, as usual. Several other furnaces were similarly furnished in and around the neighbourhood, and it was now thought that the principle of taking off the gases from a chamber above the surface of the minerals, together with the conical mode of charging, were the only indispensable conditions to success for all furnaces, and some even which were originally built too narrow at the mouth, were actually improved by the new method of charging, which did not allow of the surfaces of the minerals rising higher than about 6 feet from the top, thus giving to the furnace a diminished height, and, as a consequence of its conical shape, a wider mouth. Further experience, however, demonstrated the fallacy of this general conclusion.

" A large domed furnace was furnished with the same kind of charging apparatus which had proved so successful in former instances, but, to the astonishment of all, it turned out a complete failure, the same derangements occurring as in the former cases, where a portion of the gas only was collected by sinking a tube into the throat. Now, this furnace could not be filled to within 6 or 7 feet of the top, and at that depth the diameter was 13 feet 6 inches, owing to the sharp sweep of the dome; the actual working furnace was, therefore, 37 feet high instead of 44 feet, with a mouth 13 feet 6 inches instead of 8 feet, and as the minerals cannot lie so close against smooth sides of the walls as they do locked in each other in the more central region of the furnace, a much freer discharge of the gases up the sides must take place, and on boring a hole through the side of the furnace in the neighbourhood of the boshes, it was found that 2 feet in, the coke and other minerals were at a white heat, but a little further on towards the centre lumps of black blazing coal were found, with ironstone which had not even attained a red heat. The charging apparatus was now raised with the furnace 5 feet, and the minerals drawn up an inclined plane to the charging cup, thus enabling it to be kept full to within a short distance of the old mouth, after which the furnace worked as usual. That diminished height was not the cause of the bad working of the furnace was afterwards proved, the furnace having been blown out for repairs, and re-lined with brick-work, giving it that form and proportion deemed necessary from the experience gained, the height being now only 37 feet instead of 44, and the diameter of the mouth 7 feet 6 inches, or one-half of that at the boshes. The same charging apparatus which failed before, mounted 6 feet above the mouth, was used, and the furnace has now (1867) been working uninterruptedly for five years, turning out as much as 160 tons of grey pig-iron per week, or when burdened for white iron, 200 tons, economising the whole of its gas, and as much under the control of the manager as any furnace, either closed top or open top, can reasonably be expected to be. It is clear, therefore, that the covering of the top has nothing whatever to do with the action of a furnace kept full to the mouth, and having the proper form and proportions from that point downwards. The mouth must be understood to be that part of the furnace which represents the mean height of the surface of the minerals, and not the top of the masonry, and the question arises what proportion should that bear in diameter to the boshes or widest part, and what the latter should be with reference to height, in order to secure a maximum economical effect on the quality of the iron made and on the yield of fuel. This state of perfection can exist only when the *isothermal* lines in the furnace are parallel to the horizon, the temperature of the minerals at any given height above the tuyeres being the same through the whole horizontal sectional area at that height, and consequently arriving at the zone of fusion in an equally prepared state. If the mouth of the furnace be too wide, the heated gases have a greater tendency to pass up the sides than through the centre, thus destroying the horizontality of the lines of equal temperature, and giving them a curved form with the *convex* side downwards. Hence ores at different temperatures and of various stages of preparation, will occupy any given horizontal sectional area of the furnace; these descending together and mixing in the zone of fusion will produce evils in proportion to the extent of the deflection of the curves from a horizontal line. On the contrary, if the mouth of the furnace be too narrow in proportion to the other parts, we may expect an undue portion of the gases to pass up the centre, leaving the minerals around the sides comparatively unacted upon. It is easy to see that evils of the same kind as before must exist here, the *isothermal* lines now becoming *concave* downwards instead of *convex*, giving, as before, through any horizontal section of the furnace, ores at various temperatures, and at different degrees of deoxidation and carburation, according to the depth which they may have attained in the furnace. There are several instances of furnaces originally built with too narrow tops being greatly improved by widening them. This may conveniently be done by feeding them through a conical charger, which, by lowering the surface of the minerals, *virtually* increases the width of the mouth. On the other hand, furnaces having the opposite defect of being too wide at the top may be benefitted to some extent, provided the walls are nearly perpendicular, or do not widen too rapidly downwards, by employing as large a cone as it is possible to work in the throat; for, by the use of this feeder, the minerals must fall close to the sides, and the larger lumps roll to the axis of the furnace, and so facilitate the passage of the gases in that direction, besides giving to the surface a concave or cup form, and consequently a diminished height and resistance to the upward current in the middle. This principle of improving the charging of such defective furnaces is even carried out to some extent in feeding open top furnaces where the gases are wasted. The charging plate is so placed as to prevent the nose of the barrow from projecting any distance into the furnace. The minerals being thus discharged close to the edge, the larger lumps have a tendency to roll over towards the centre, leaving the smaller at the ring walls, to check the upward current in that direction.

"The above considerations will materially assist in furnishing an answer to the oft-repeated and very important question, 'What form and proportions should a blast furnace have to produce the best results in quality of iron, and in economy of fuel, whether worked on the open top principle, or enclosed for the purpose of utilising the waste gases?' Experience has proved that when the mouth of the furnace is one-half the diameter of the widest part, good work is obtained, and that any deviation from that proportion, if in excess, has been productive of great derangement in its action. The height of the furnace should also bear a certain proportion to the greatest diameter, in order to secure an uniform flow of the ascending current through all its parts, for if the widest part bear too great a relation to the height, the boshes must necessarily be of a low angle, and, consequently, the minerals around the sides near their top be at too great a distance out of the direct line of passage of the ascending current, and consequently remain only partially prepared for fusion. The proportions recommended by Mr. Parry, and which have been practically tested, most satisfactorily in several instances, are as shown in Fig. 96. The mouth, *b′*, *b′*, one-half the diameter of the widest part, *c*, *c*, and this should not be at a less depth than its own diameter. The sides of the furnace to this depth should be formed slightly dome-fashioned, for the purpose of giving to that region a larger capacity than would be obtained by a conical form. The radius of the curve should be at right angles to the axis of the furnace, and formed by a prolongation of the line representing the greatest diameter. When the radius is set at a great angle with this line, which is often done to give greater capacity to the domed part, the distortion produced by the sharpness of the curve may leave a segment of the minerals unacted upon by the gases in their passage to the mouth, and entail greater evils than would be compensated for by increased capacity. The curve is continued below the widest part of the furnace, till it meets the top of the boshes, *d*, *d*, the angle of which should not be less than 70°, and start from the point of the tuyeres, *f*, *f*. The depth,

FIG. 96.



also, from the widest part to the tuyeres should not be less than its own diameter, *plus* half the diameter of the tuyeres. These proportions give a blast furnace, of any determinate height fixed upon, the largest possible capacity it is capable of receiving, while remaining free from any distortion of form, likely to give a place for minerals to lie out of the way of the action of the upward gaseous current; when the height exceeds the proportion to its greatest diameter indicated in the figure, an unnecessary sacrifice in its capacity is the only loss entailed. The height above the mouth must be regulated by the kind of hopper used for charging, where it is intended to carry off the gases.

"Doubtless, when the true principle of collecting these gases without injury to the blast furnace becomes more generally known, attention will be directed to the easiest and most convenient mode of introducing the minerals. The conical charger has only one disadvantage, that, namely, of allowing a great waste of gas during the charging; probably some kind of revolving hopper may be contrived to remedy this defect. It is, of course, assumed that the furnace is supplied with a proper quantity of blast, and of a density proportionable to the diameter across the tuyeres, so as to maintain a vigorous combustion of the fuel to the very centre of the hearth, the top of which is indicated by the letters *e*, *e*, for unless this is attained, a cold cone of minerals will remain in the centre, and produce derangements which no degree of perfection in the form of the furnace in the higher region can remove."

Wherever the space will allow it, the waste gases are utilised at the level, or above the furnace mouth, as is the case in many charcoal furnaces. The head of most large coke furnaces, however, is not surrounded with a platform sufficiently large to contain boilers and hot air ovens, the gases are therefore conducted to the sole of the furnace and here utilised; this also takes place in cases where the gases are utilised in heating the blast, intending at the same time to use blast pipes of the shortest possible length, in order to avoid loss in power. For the latter reason, the hot blast apparatus in Vordernberg, which was formerly placed at the level of the furnace head, has been removed to the sole of the furnace, and the gain in power is so considerable that the blast now produced more easily suffices for four tuyeres than it formerly did for three, whilst all the conditions of the blast engines were, in both cases, the same.

The draught required for conducting the gases downward to the floor of the furnace must be induced by means, of large chimneys, which must increase in height in proportion with the distance to which the gases have to be conducted.

The apparatus in which the gases are used as fuel are frequently provided with separate grates, allowing the application of compact fuel; these grates are used when the waste gases, for some reason or another, are insufficient either in quantity or quality.

In burning the gases, care must be taken to prevent explosions, which are very likely to occur when the gases become mixed with atmospheric air; the lid of a furnace must not be suddenly closed after the charging has taken place, as by this means air is liable to be pressed into the gas channels; the gases must, furthermore, be ignited as soon as they enter the space to be heated. If this ignition does not take place spontaneously, some fire is to be kept for the purpose on the grate.

The gases are burnt either by means of air draught or by blast. The latter is employed in hot blast apparatus at Thiergarten,* in Baden, where the precaution is taken to obstruct the escape of the gases from the apparatus by a sliding valve, so as to impart to them a certain pressure; in ascending in the blast furnace the gases are thus obliged to pass into all empty spaces, which promotes their uniform ascent, and equalises the reduction of the ores.

When air draught is employed for burning the gases, the air is introduced either by means of channels, or the gases are conducted across a grate, which admits the air required; the admission of the air is regulated by the ash lying on the grate. More complicated contrivances are, frequently, not more effectual than the simple grate. At Vordernberg, where the gases pass across the grate with low pressure, the steam is first produced by heating with wood or brown coal, when the gases are employed for heating boilers; when they are used for heating hot air ovens, a small fire for a few hours at the commencement is sufficient to produce the draught which is required for the avoidance of explosions, and also for the re-ignition of the gases which, in the first period, are very liable to become extinguished.

One disadvantage of the employment of the waste gases is the interruption to which the current of gas is subjected; these interruptions are caused by the charging of the furnace, by the insertion of new tuyeres into the furnace, &c., and if they are prolonged, combustion has to be sustained by the aid of other kinds of fuel.

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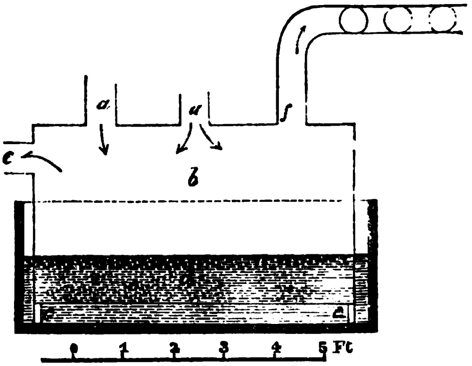
* **Bericht über die erste allgemeine Versammlung von Berg- und Hüttenmännern zu Wien, 1859, p. 70.**

In working ores containing zinc, the gas channels are frequently obstructed by an accumulation of oxide of zinc, and the evaporated substances contained in the waste gases (less so in the generator gases) coat the apparatus to be heated, or narrow the gas channels, causing the current of gas to become irregular, and necessitating a more frequent cleaning of the gas tubes. In order to liberate the gases from such substances, and in cases where they are conducted down to the sole of the furnace, special *washing apparatus* have lately been frequently employed, and their purifying and cooling effect has brought the use of the gases to considerable perfection.

**Washing Apparatus.**—The following examples show the construction of these apparatus :—

The gases in the iron works at Gaya,* in Moravia, are collected in an annular space 6 inches wide, formed by a cylinder with which the furnace throat is provided ; through a channel in the furnace walling, the gases enter a tube, which, some feet deeper, is divided into two smaller pipes, which at *a* (Fig. 97) conduct the gases into the reservoir, *b*, of iron plate, and standing on the sole of the furnace. The reservoir below is open, and rests on four iron feet, *c*, upon

FIG. 97.



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* B. u. h. Ztg., 1860, p. 148.

the bottom of the wooden vessel, *d*, which is partially filled with water. The gases entering the reservoir, *b*, cool and purify above the water, and they issue through the tubes, *e* and *f*, which are provided with sliding valves. The tube, *e*, is connected with the hot air apparatus, and the tube, *f*, conducts the gases to three boilers, by means of three branch tubes, one for each boiler; these branch pipes are provided with sliding valves; after the gases have been burnt, they escape into a chimney 90 feet high.

Fig. 98.

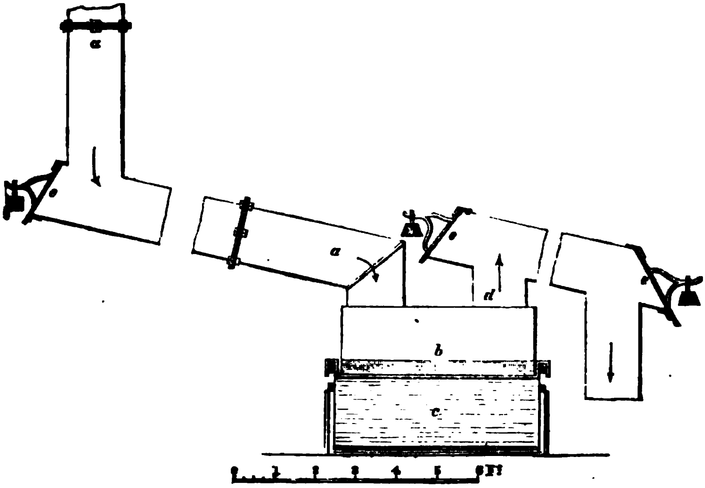
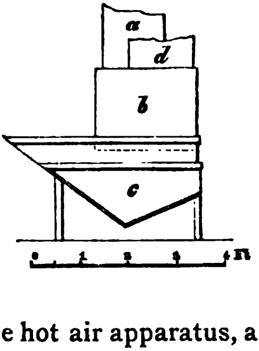


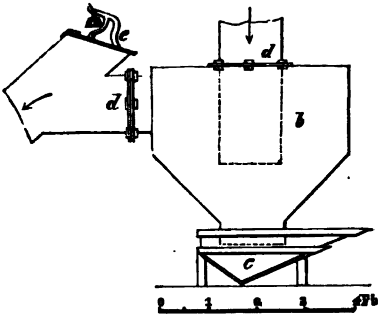
Fig. 99.



The apparatus represented in Figs. 98 and 99 is advantageously used at Vordernberg.* The gases are collected from the blast furnace by means of an iron cylinder hanging in the furnace mouth, and are conducted to the sole of the furnace by means of the tube, *a*, where they enter the reservoir, *b*, which stands in the vessel, *c*. The gases issue again through the tube, *d*. The safety valves, *e*, are chiefly used for cleaning the apparatus, and are less intended to give security against explosions, as these may be prevented by a careful treatment. The furnace dust collecting in the vessel, *c*, is removed from time to time.

A somewhat more simple apparatus is shown in Fig. 100.

FIG. 100.



*a* is the gas tube conducting the waste gases into the reservoir, *b* ; *c* is a vessel containing water ; *d* is the tube for conducting the gases to their place of combustion ; *e* is a safety valve.

A very effective contrivance, shown in Fig 101, and which is also applied in the iron works at Vordernberg, consists in an arrangement by which the gases are conducted through the pipes, *a* and *b*, and made to circulate in the vessels, *c* and *d*, whence they issue through the tube, *e*.

### Examples of the Utilisation of the Waste Gases.

The blast furnace at the Quint,† near Trier, contains suspended on its throat, a cylinder 6 feet high and 5 feet wide, made of iron plate ¼ inch thick. The gases collect in the space between the cylinder and the furnace walling, which

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* RITTINGER'S Erfahrungen, 1858, p. 31.

† B. u. h. Ztg., 1858, p. 234.

FIG. 101.

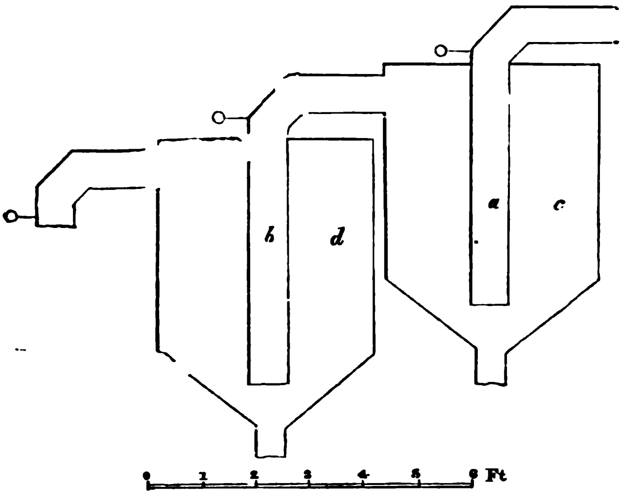
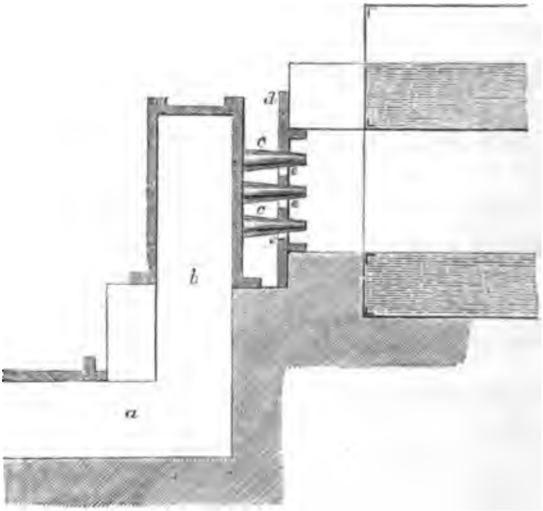


FIG. 102.



is 9 inches wide, and are conducted into a cast-iron reservoir through a tube 27 inches broad and 18 inches high; two tubes of sheet-iron, 18 inches in diameter, conduct the gases from the reservoir to the sole of the building which contains the boilers, and which lies 12 feet deeper than the reservoir. Each of these tubes enters into a walled-up channel, *a* (Fig. 102), the top of which is covered with iron plates; sand is thrown on the plates to keep them tight. From the channel, the gases enter the reservoir, *b*, which is made of cast-iron plates, screwed together; that plate of the reservoir facing the boiler contains, in three rows, about thirty tuyeres, *c*, 6 inches long, which pass through openings in the plate, *d*; for the admission of the air of combustion, the openings, *e*, are notched somewhat larger, leaving an open space round the tuyeres. A sheet-iron chimney, 70 feet high, produces the draught required. The gases burn in the fire-tube, *f*.

More simple than this arrangement for combustion are those methods in which the gas is conducted across a grate containing some burning fuel; these methods are employed at Geislautern,* at Friedrichs Wilhelmshütte,† in Mühlheim on the Ruhr, at Vordernberg,‡ &c.

The blast furnaces at Vordernberg, producing weekly 2000 and 3000 cwts. of pig-iron respectively, yield a larger quantity of waste gases than is sufficient for heating the blast and boilers and for roasting the ores. Cylinders of iron plates, 30 inches wide and 6½ feet high, are suspended in the furnaces, and the gases are drawn off 18 inches below the furnace mouth, and conducted to the sole of the furnace through tubes 18 inches wide; the furnace mouth is not otherwise closed. Before being conducted to their places of combustion, the gases are made to pass through washing apparatus, as shown on page 524, in Figs. 98—100, their surface of water comprising 12 square feet.

The hot blast apparatus‖ is heated in the following manner, as shown in Figs. 103 and 104. The purified gases are conducted into the cast-iron box, *a*, and hence into the fire-place above the grate, *c*, through the slit-like opening, *b*;

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* B. u. h. Ztg., 1858, p. 235.

† Ibid.

‡ Oesterr. Ztschr., 1855, No. 52. B. u. h. Ztg., 1856, p. 90.

‖ RITTINGER's Erfahrungen, 1858, p. 31.

at the commencement of an operation, some burning coals are thrown on the grate. The sliding door in *d* is gradually

FIG. 103.

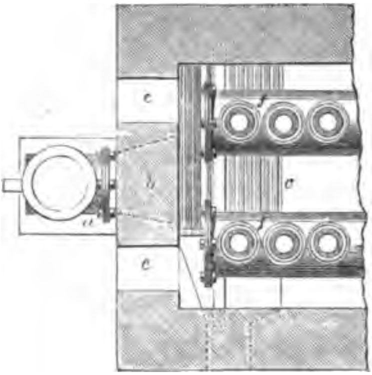
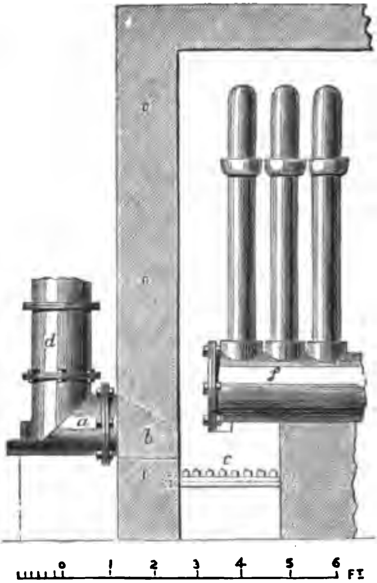


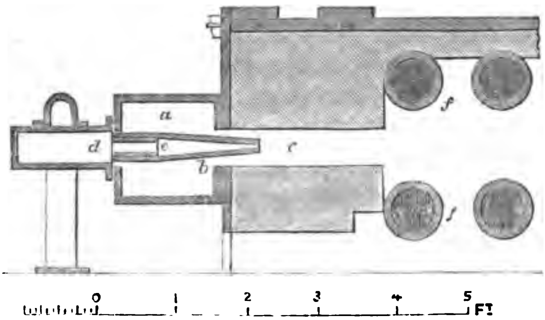
FIG. 104.



opened, but not before the gases, at this place, become clearly perceptible by the smell; they first enter in a small quantity, and ignite at once. The air of combustion enters the closed doors, *e*, otherwise used for cleaning the apparatus, and the draught required is induced by a chimney 72 feet high. No apprehension need be felt lest the strong draught should draw too many gases from the furnace, as the current of gas may be regulated at will; *f* represents the hot blast apparatus.

At Thiergarten,* in Baden, the waste gases are burnt by means of hot blast. The gases are collected 8 or 9 feet below the furnace mouth, and conducted into a cast-iron reservoir, *a*, shown in Fig. 105, hence the gases pass through the slit, *b*, and are mixed with hot blast in the chamber, *c*; the hot blast is conducted into the reservoir, *d*, from which it issues through the tuyeres, *e*. After having heated the blast pipes, *f*, the burnt gases escape at the back of the apparatus, passing partly into a chimney, and partly into ovens for drying wood.

FIG. 105.



Various examples of the utilisation of the waste gases, as well as the instructive experiments made by Thomas and Laurens concerning the collection, washing, and burning of the waste gases, are communicated in Peclet, die Anwendung der Wärme, deutsch von Hartmann, 1860, Bd. i., p. 255.

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* Bericht über die erste allgem. Versammlung von Berg-und Hüttenmännern in Wien, 1859, p. 67.

## B. Generator Gases.*

We have before observed, that the application of the waste gases as fuel has led to the conversion of compact fuel into gases, that is, those kinds of compact fuel which, owing to their richness in ash, state of aggregation, &c., do not admit of a direct application, whilst the gases produced from them, on a judicious combustion, yield the desired effect.

Sometimes, also, it is most advantageous to utilise good kinds of compact fuel in this manner, as they then yield a heating power which nearly approaches that of the theoretical calculation.

In countries where mineral coal does not abound, or is too expensive, the only rational way of carrying on metallurgical operations is by means of artificially-produced gas.

**Production of the Gases.**—The conversion of the compact fuel into gas is effected in a kind of small shaft furnace (gas generators), which is partially filled with the compact fuel. Air is conducted into the lower part of the generator by means of draught or blast, thus producing carbonic acid and carbonic oxide in variable proportions, according to the compactness of the fuel, pressure of the air of combustion, &c. The ascent of the gases through the upper layers of heated fuel, the thickness of which varies according to the quality and size of the fuel, transforms the carbonic acid into carbonic oxide,† which is conducted in a suitable manner from the upper part of the generator into a fire-place, where it is burnt either by means of hot or cold draught or blast. The carbonic oxide gas thus produced is rendered impure by the nitrogen of the air of combustion, and contains more or less carburetted hydrogen and hydrogen, owing to a dry distillation which takes place in the upper layers of the fuel, or to the decomposing reaction of the watery vapours formed. The gases are more frequently drawn off from above than from below.

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* Literatur über Benutzung der zu metallurgischen und technischen Zwecken selbstständig erzeugten Gase in Zerrenner's met. Gasfeuerung: Wien, 1856. Hartmann, über den Eisen- Kupfer- Zink- und Bleihüttenbetrieb mit brennbaren Gasen, Heft 1—3, 1844, 1845, 1850. Bischof, ii., die indirecte Nutzung der rohen Brennmaterialien: Quedlinburg, 1858. Le Play, Grundsätze: Freiberg, 1854. Lan, in B. u. h. Ztg., 1857, p. 15. Gruner, in B. u. h. Ztg., 1857, p. 23. Thoma, in B. u. h. Ztg., 1851, p. 1; 1857, p. 15. Peclet, Anwendung der Wärme, deutsch v. Hartmann, 1860, Bd. i. p. 255.

† Erdm., J. f. pr. Ch., lv., 399; lviii., 483. Peclet, c. i., p. 280.

**Composition of the Generator Gases.**—The composition of the generator gases varies according to the quality of the material employed, and their larger or smaller proportion of carbonic acid depends chiefly on the compactness and state of division of the fuel, as well as on the thickness of the layer of fuel in the generator, and the depth from which the gases are drawn off. When intending to convert the carbonic acid into carbonic oxide as perfectly as possible, the thickness of the layer of fuel must amount at least to from 2 to 4 feet, and this conversion is mainly influenced by the compactness of the fuel, and the size of the pieces; it is likewise promoted by offering a large surface to the ascending acid. Supposing that the perfect conversion of carbonic acid into oxide required a thick layer of burning coal, the first generators were constructed too high; Ebelmen's analyses have proved that a height of 1 foot is sufficient, even at a low pressure of the blast, and especially when hot air is employed. Thomas and Laurens state that coke and mineral coal require greater heights, up to 3 metres.*

Scheerer asserts that the generator gases, by weight, have the following composition and theoretical heating power:—

| | Wood. | | Peat. | Charcoal. | Coke. |
|---|---|---|---|---|---|
| | I. | II. | | | |
| Nitrogen . . | 53·2 | 55·5 | 63·1 | 64·9 | 64·8 |
| Carbonic oxide | 34·5 | 21·2 | 22·4 | 34·1 | 33·8 |
| Carbonic acid. | 11·6 | 22·0 | 14·0 | 0·8 | 1·3 |
| Hydrogen . . | 0·7 | 1·3 | 0·5 | 0·2 | 0·1 |
| Total. . . | 100·0 | 100·0 | 100·0 | 100·0 | 100·0 |
| Absolute heating power | 0·095 | 0·084 | 0·063 | 0·079 | 0·075 |
| Specific „ „ | 0·000124 | 0·000109 | 0·000082 | 0·000103 | 0·000098 |
| Pyrometric „ „ | 1325° C. | 1165° C. | 1070° C. | 1260° C. | 1240° C. |

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* Peclet, c. i., pp. 260, 280.

The heating power of the gases increases with their temperature and richness in carbonic oxide, with the dryness of the fuel employed, with the proportion of carbon contained in the fuel, and with the temperature of the air of combustion. These circumstances admit of the production of temperatures sufficiently high to puddle and re-heat iron.

According to Tunner,* the gases produced from brown coal, when without any pressure, produce a theoretical heating power up to 2600° C.

In burning carbon to carbonic acid (page 336) a temperature of 2458° C. is produced, which, however, decreases by about 1200° C. in converting the carbonic acid into oxide; the firing with gaseous fuel necessitates, therefore, under all circumstances, a great sacrifice of temperature (absolute heating power). This sacrifice must be made in all cases where the production of a high temperature is intended (pyrotechnic effect), and where the material employed does not admit of a direct combustion to carbonic oxide. Firing with gas is, therefore, less advantageous when the object is to produce large quantities of heat, more than high temperatures.†

Mr. C. W. Siemens has made the following statements with regard to his regenerative gas furnaces:—

"The regenerative gas furnace consists of two essential parts.

"The gas producer, in which the coal or other fuel used, is converted into a combustible gas, and

"The furnace, with its 'regenerators,' or chambers for storing the waste heat of the flame, and giving it up to the in-coming air and gas.

"Any combustible gas might be burned in the regenerative furnace. I have used ordinary lighting gas very successfully, on a small laboratory scale, but it is far too costly to be employed in larger furnaces, and the only gas generally available, is that generated by the complete volatilisation of coal, wood, or other fuel, with admission of air, in a special 'gas producer.' Any description of carbonaceous matter may be worked in a suitable gas producer, and will afford gas sufficiently good for the supply of even those furnaces in which the highest heat is required. Coal is the fuel chiefly used for gas furnaces in England; small coke has been employed in some cases, as in gas works, where it is to be had at a cheap rate; wood is used in France, Bohemia, and Spain; sawdust in Sweden, furnishing gases for welding and other high heat furnaces; lignite in various parts of Germany; and peat in Italy and elsewhere; this last being applicable with the greatest relative advantage."

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* Oesterr. Ztschr., 1859, No. 15.

† Ibid., 1859, pp. 65, 163. B. u. h. Ztg., 1859, p. 420.

Siemens's gas producer or generator is shown in Fig. 245 of our second volume (page 794).

" Air is admitted at the grate, and as it rises slowly through the ignited mass, the carbonic acid, first formed by the combination of the oxygen with the carbon of the fuel, takes up an additional equivalent of carbon, forming carbonic oxide, which, diluted by the inert nitrogen of the air and by a little unreduced carbonic acid, and mixed with the gases and vapours distilled from the raw fuel during its gradual descent towards the grate, is led off by the gas flue to the furnace. The ashes and clinkers that accumulate on the grate are removed at intervals of one or two days.

" The composition of the gases varies with the nature of the fuel used, and the management of the gas producer. That of the gas from the producers at the Plate Glass Works, St. Gobain, France, burning a mixture of three quarters caking coal and one quarter non-caking coal, is as follows, by an analysis dated July, 1865:—

| | Volumes. |
|---|---|
| Carbonic oxide | 23·7 |
| Hydrogen. | 8·0 |
| Carburetted hydrogen | 2·2 |
| Carbonic acid | 4·1 |
| Nitrogen | 61·5 |
| Oxygen | 0·4 |
| | 99·9 |

The trace of oxygen present is, no doubt, due to carelessness in collecting the gas, or to the leakage of air into the flue, and, allowing for this, the corrected analysis will stand as under :—

| | Volumes. | |
|---|---|---|
| Carbonic oxide | 24·2 | 34·6 |
| Hydrogen | 8·2 | |
| Carburetted hydrogen | 2·2 | |
| Carbonic acid | 4·2 | 65·4 |
| Nitrogen | 61·2 | |
| | 100·0 | |

Only the first three of these constituents, say 35 per cent of the whole, are of any use as fuel, the nitrogen and carbonic acid present only diluting the gas. It is the large proportion of inert gases which must be heated to the full temperature of the flame, that renders it so difficult to maintain a high heat by gas of this description burnt in the ordinary way. In using such gas in a regenerative furnace, the presence of so large an amount of nitrogen is not objectionable, as the heat it carries off is given up again to the air and gas coming in.

" The gas, as it passes off from the fuel, contains also more or less aqueous vapour, which is got rid of by cooling it, with some tar and other impurities, and a small quantity of suspended soot and dust.

" Any unburnt air drawn in through a hole in the mass of fuel reduces the value of the gas by burning the carbonic oxide again to carbonic acid. To prevent the in-draught of air in this way at the side of the grate, I have found it very advantageous to set the side walls of the gas producer back, forming a broad step about 9 or 10 inches above the grate ; any air creeping up along the wall is thus thrown into the mass of fuel and completely burnt. The effect of this feature in the form of the producer on the quality of the gas has been very striking.

" Three-tenths of the total heat of combustion of solid carbon are evolved in burning it to carbonic oxide ; but in the gas producer a small portion only of this heat is really lost, because it is in a great measure taken up and utilised in distilling the tar and hydrocarbon gases from the raw fuel, and it may be still further economised, especially in burning such a fuel as coke or anthracite, which contains little or no volatile matter, by introducing a regulated supply of steam with the air entering at the grate. This is effected very simply by keeping the ash-pit always wet. The steam is decomposed by the ignited coke, and its constituents, hydrogen and oxygen, are re-arranged as a mixture of hydrogen and carbonic oxide, with a small variable proportion of carbonic acid. Each cubic foot of steam produces nearly two cubic feet of the mixed gases, which, being free from nitrogen, have great heating power, and form a valuable addition to the gas. The proportion of steam that can be advantageously introduced into the gas producer is, however, limited, as it tends to cool the fire, and if this is at too low a heat, much carbonic acid is produced instead of carbonic oxide, causing waste of fuel.

" From the high temperature of the gas as it rises from the fuel (1000° F. to 1300° F.), and from its comparatively low specific gravity, it is considerably lighter than atmospheric air, and ascends into the upper part of the producer with a slight outward pressure. It is necessary to maintain this pressure through the whole length of the gas flue, in order to ensure a free supply of gas to the furnaces, and to prevent its deterioration in the flue through the in-draught of air at crevices in the brick-work. The slight loss of gas by leakage, which results from a pressure in the flue, is of no moment, as it ceases entirely in the course of a day or two, when the crevices become closed by tar and soot.

" Where the furnace stands so much higher than the gas producer that the flue may be made to rise considerably, the required plenum of pressure is at once obtained; but more frequently the furnaces and gas producers are placed nearly on the same level, and some special arrangement is necessary to maintain the pressure in the flue. The most simple contrivance for this purpose is the 'elevated cooling tube.' The hot gas is carried up by a brick stack to a height of 8 or 10 feet above the top of the gas producer, and is led through a horizontal sheet-iron cooling tube, of no less than 60 square feet of surface per gas producer, from which it passes down either directly to the furnace, or into an underground brick flue.

"The gas rising from the producer, at a temperature of about 1100° F., is cooled as it passes along the overhead tube, and the descending column is consequently denser and heavier than the ascending column of the same length, and continually overbalances it. The system forms, in fact, a syphon, in which the two limbs are of equal length, but the one is filled with a heavier fluid than the other. The height of the cooling tube required to produce as great a pressure in the flue as would be obtained by placing the gas producers, say ten feet deeper in the ground, may be readily calculated. The temperature of the gas as it rises from the producers has been taken as 1100° F., and we may assume that it is cooled in the overhead tube to 100° F., an extent of cooling very easily attained. The calculated specific gravity, referred to hydrogen, of the gas of which I have quoted the analyses, being 13·14, we obtain the following data:—

lb.
Weight of the gas per cubic foot at 1100° F. = 0·022
" " " 100° F. = 0·061
" atmospheric air per cubic foot at 60° F. = 0·076

and from these we have, on the one hand, the increase of pressure per foot of height, in a flue rising directly from the gas producer—

= 0·076 − 0·022 = 0·054 lb. per square foot;

and, on the other hand, the excess of pressure at the foot of the downtake from the cooling tube, over that at the same level in the flue leading up from the gas producer (for each foot in height of the cooling tube)—

= 0·061 − 0·022 = 0·039 lb. per square foot.

The height of the cooling tube above the level of the flue that will be sufficient to produce the required pressure, equal to 10 feet of heated gas column, is therefore—

$\frac{0{\cdot}054}{0{\cdot}039} \times 10$ feet = 13 feet 10 inches, or, say 14 feet.

"This method of obtaining a pressure in the gas-flue by cooling the gas has been objected to, as throwing away heat that might be employed to more advantage in the furnace; but this is not the case, because the action of a regenerator is such that the initial temperature of the gases to be heated has no effect on the final temperature, and only renders the cooling of the hotter fluid more or less complete. The only result, therefore, of working the furnace with gas of high temperature, is to increase the heat of the waste gases passing off by the chimney flue. The complete cooling of the gas results, on the other hand, in the great advantage of condensing the steam that it always carries with it from the gas producer, and in the case of iron and steel furnaces, in burning wet fuel, it is absolutely necessary to cool the gas very thoroughly in order to get rid of the large amount of steam that it contains, which, if allowed to pass on to the furnace, would oxidise the metal.

" There is, undoubtedly, a certain waste of heat which might be utilised by surrounding the cooling tube with a boiler, or by otherwise economising the heat it gives off, as, for instance, in drying the fuel; but the saving to be effected is not very great, for as 100 volumes of the gas require for combustion about 130 volumes of air, including 20 per cent above that theoretically required, the heat given off in cooling 1000° is no more than would be lost in discharging the products of the complete combustion of the fuel, at a temperature 435° in excess of the actual temperature of 200°, and this loss is greatly diminished if a richer gas is obtained.

" In erecting a number of gas producers and furnaces, I generally prefer to group the producers together, leading the gas from all into one main flue, from which the several furnaces draw their supplies. The advantages of this are—saving of labour and convenience of management, from the gas producers being all close together, and greater regularity in working, as the furnaces are seldom all shut off at once; nor is it likely that they will require at the same time an exceptional amount of gas.

" From the fact that the gas producers may be at any distance from the furnaces which they supply, if they are only at a lower level, it would be perfectly practicable to erect them in the coal mine itself, burning the slack and waste coal *in situ* (in place of leaving it in the workings, as is now often done), and distributing the gas by culverts to the works in the neighbourhood, instead of carrying the coal to the different works, and establishing special coal producers at each. In rising to the mouth of the pit, the gas would acquire sufficient pressure to send it through several miles of culvert.

"In the regenerative furnace, the gas and air employed are separately heated by the waste heat of the flame, by means of what are termed 'regenerators,' placed beneath the furnace. These are four chambers, filled with fire bricks, stacked loosely together, so as to expose as much surface as possible; the waste gases from the flame are drawn down through two of the regenerators, and heating the upper rows of bricks to a temperature little short of that in the furnace itself, pass successively over cooler and cooler surfaces, and escape at length to the chimney flue, nearly cold. The current of hot gases is continued down through these two regenerators until a considerable depth of brickwork, near the top, is uniformly heated to a temperature nearly equal to that of the entering gases, the heat of the lower portion decreasing gradually downwards, at a rate depending on the velocity of the current and the size and arrangement of the bricks. The direction of the draught is then reversed; the current of the flame or hot waste gases are employed to heat up the second pair of regenerators, and the gases and air entering the furnace are passed in the opposite direction through the first pair, and coming into contact, in the first instance with the cooler brickwork below, are gradually heated as they ascend, until, at some distance from the top, they attain a temperature nearly equal to the initial heat of the waste gases, and passing up into the furnace, meet and at once ignite, producing a strong flame, which, after passing through the heating chamber, is drawn down through the second pair of regenerators to the chimney flue. The temperature attained by the ascending gas and air remains nearly constant, until the uppermost courses of the regenerator brick work begin sensibly to cool; but, by this time, the other two regenerators are sufficiently heated, and the draught is again reversed, the stream of waste gases being turned down through the first pair of regenerators, re-heating them in turn, and the gas and air which enter the furnace being passed up the second. By thus reversing the direction of the draught at regular intervals, nearly all the heat is retained in the furnace, that would otherwise be carried off by the products of combustion, the temperature in the chimney flue rarely exceeding 300° F., whatever may be the heat in the furnace. The proportion of heat carried off in an ordinary furnace by the products of combustion, is generally far greater than that which can be utilised, as all the heat of the flame below the temperature of the work to be heated, is absolutely lost. The economy of fuel effected in the regenerative gas furnace, by removing this source of loss, and making all the heat of the waste gases, however low its intensity, contribute to raise the temperature of the flame, amounts, in average practice, to fully 50 per cent on the quantity used in an ordinary furnace, and the saving is greater, the higher the heat at which the furnace is worked. In addition to this economy in the amount of fuel used, a much cheaper quality may generally be burnt in the gas producer than could be used in a furnace working at the same heat, and in which the fuel is burnt directly upon the grate in the ordinary way.

"When the heat of the furnace is not abstracted continually by cold materials charged into it, the temperature necessarily increases after each reversal, as only a very small fraction of the heat generated is carried off by the waste gases. The gas and air, in rising through the regenerators, are heated to a temperature nearly equal to that at which the flame had been passing down; and when they meet and burn in the furnace, the heat of combustion is added to that carried up from the regenerators, and the flame is necessarily hotter than before, and raises the second pair of regenerators to a higher heat. On again reversing, this higher heat is communicated to the gas and air passing in, and a still hotter flame is the result. The temperature that may be attained in this way by the gradual accumulation of heat in the furnace, and in the upper part of the regenerators, appears to be quite unlimited, and the heat at which a suitably designed furnace can be worked, is limited in practice only by the difficulty of finding a material sufficiently refractory of which it can be built.

"Welsh Dinas brick, consisting of nearly pure silica, is the only material, of those practically available on a large scale, that I have found to resist the intense heat at which steel melting furnaces are worked; but though it withstands perfectly the temperature required for the fusion of the mildest steel, even this is melted easily if the furnace is pushed to a still higher heat.

"The following is an analysis of Dinas 'clay' from Pont-Neath-Vaughan, Vale of Neath (Percy's Metallurgy, vol. i., p. 237):—

| | |
|---|---|
| Silica | 98·31 |
| Alumina | 0·72 |
| Protoxide of iron | 0·18 |
| Lime | 0·22 |
| Potassa and soda | 0·14 |
| Water (combined) | 0·35 |
| | 99·92 |

The 'clay' is mixed with 1 per cent of lime in making the bricks.

"As the gas flame is quite free from the suspended dust which is always carried over from the fuel by the keen draught of an ordinary furnace, the brick work exposed to it is not fluxed on the surface, and gradually cut away, but fails, if at all, only from absolute softening and fusion throughout its mass. A Stourbridge brick, for example, exposed for a few hours to the heat of the steel melting furnace, remains quite sharp on the edges, and is little altered even in colour; but it is so thoroughly softened by the intense heat, that on attempting to take it out, the tongs press into it and almost meet, and it is often pulled in two, the half-fused material drawing out in long strings. It results from this perfect purity of the flame, that where the heat is not sufficient to effect the absolute fusion of the bricks employed, the length of time is almost unlimited during which a gas furnace will work without repairs.

"Another advantage in employing the fuel in the manageable form of gas, is that the rate of combustion may be regulated, at pleasure, to produce an active heating flame of any length, from little more than 2 feet, as in the pot steel-melting furnaces, to 30 feet in the largest furnaces for the fusion of plate glass; and the most intense heat may be thrown exactly upon the charge, the ends of the furnace and the apertures through which the gas and air are introduced being actually protected from the heat by the currents of unburnt, and comparatively cool, gases flowing through them, and only mixing and burning at the very point at which the heat is required, and where it is taken up at once by the materials to be fused or heated. This is of special importance in the case of those furnaces in which a very intense heat is employed.

"The amount of brickwork required in the regenerators to absorb the waste heat of a given furnace, is a matter of simple calculation. The products of the complete combustion of 1 lb. of coal have a capacity for heat equal to that of nearly 17 lbs. of fire-brick. Taking the analysis, by Vaux, of the celebrated ten-yard coal of Staffordshire (Watts's 'Dictionary of Chemistry,' i., 1081) the exact calculation is as follows:—

| Composition of the Coal. | | | Oxygen required. |
|---|---|---|---|
| Carbon . . . | 0·7857 | × $\frac{8}{3}$ | 2·0952 |
| Hydrogen . . | 0·0529 | × 8 | 0·4232 |
| Sulphur. . . | 0·0039 | × 1 | 0·0039 |
| Nitrogen . . | 0·0184 | | 2·5223 |
| Oxygen. . . | 0·1288 | less | 0·1288 |
| Ash . . . . | 0·0103 | | |
| | | Net oxygen required | 2·3935 |
| | 1·0000 | 20 per cent excess | 0·4787 |
| | | Total oxygen . . . . . | 2·8721 |
| | | Corresponding nitrogen . | 9·6160 |
| | | Nitrogen in the fuel . . | 0·0180 |
| | | Total Nitrogen . . . . | 9·6340 |

| Gas produced from 1 lb. of Coal. | | Specific Heats. | Equivalent Weight of Water. |
|---|---|---|---|
| Carbonic acid . . . | = 2·881 | 0·217 | 0·625 |
| Water (steam) . . | = 0·476 | 0·480 | 0·228 |
| Sulphurous acid . . | = 0·004 | 0·154 | 0·001 |
| Oxygen in excess . | = 0·479 | 0·218 | 0·104 |
| Nitrogen . . . . . | = 9·634 | 0·244 | 2·350 |

Total equivalent weight of water . . . 3·308
Total equivalent weight of fire brick (sp. heat 0·2) . . . . . . . . . 16·540

"In reversing every hour, 17 lbs. of regenerator brick-work, at each end of the furnace, per lb. of coal burnt in the gas producer per hour, would be theoretically sufficient to absorb the waste heat, if the whole mass of the regenerator were uniformly heated at each reversal to the full temperature of the flame, and then completely cooled by the gases coming in; but, in practice, by far the larger part of the depth of regenerator chequer-work is required to effect the gradual cooling of the products of combustion, and only a small portion near the top, perhaps a fourth of the whole mass, is heated uniformly to the full temperature of the flame; the heat of the lower portion decreasing gradually downwards, nearly to the bottom. Three or four times as much brick-work is thus required in the regenerators, as is equal in capacity for heat to the products of combustion.

"The best size and arrangement of the bricks is determined by the consideration of the extent of opening required between them, to give a free passage to the air and gas, and by the rule, deduced from my experiments on the action of regenerators in 1851-52,* that a surface of 6 square feet is necessary in the regenerator to take up the heat of the products of combustion of 1 lb. of coal in an hour.

"By placing the regenerators vertically, and heating them from the top, the heating and cooling actions are made much more uniform throughout than when the draught is in any other direction, as the hot descending current, on the one hand, passes down most freely through the coolest part of the mass, while the ascending current of air or gas to be heated rises chiefly through that part which happens to be hottest, and cools it to an equality with the rest. The regenerators should always be at a lower level than the heating chambers, as the gas and air are then forced into the furnace by the draught of the heated regenerators; and it may be worked to its full power, either with an outward pressure in the heating chamber, so that the flame blows out on opening the doors, or with the pressure in the chamber just balanced, the flame sometimes blowing out a little and sometimes drawing in. The outward pressure of the flame prevents that chilling of the furnace, and injury to the brick-work, from the in-draught of cold air through crevices, which is otherwise unavoidable in any furnace worked without blast.

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* Proceedings of the Institution of Civil Engineers, 1852-3, page 571, "On the Conversion of Heat into Mechanical Effect."

"The action of the furnace is regulated by the chimney damper and by valves governing the supply of gas and air, and the draught is reversed by cast-iron reversing valves, on the principle of the common four-way cock."

**Comparison of the Generator Gases with the Waste Gases and the Ordinary Flame.**—The flame of the generator gases yields a greater heat than that of the waste gases, as the latter vary a great deal in composition, and are contaminated with dust of silica, &c. The waste gases also contain but little carburetted hydrogen, whilst the generator gases frequently possess more than 15 per cent of this substance, in consequence of which, their heating power is greater, and, owing to the large proportion of combustible gases which the generator gases contain, they have the property of oxidising and reducing according to the quantity of air of combustion admitted. Firing with generator gases is also far more advantageous than the ordinary mode of direct firing, which, owing to the very frequently imperfect and irregular combustion, is liable to produce a smoky and dusty flame, sometimes containing an excess of oxygen, and sometimes an excess of carburetted hydrogen.

The condition next in importance to the construction of the generators or gas producers and furnaces, is the employment of dry fuel.*

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* B. u. h. Ztg., 1857, p. 16. PECLET, c. i., p. 262.

**Materials for the Production of Gases.**—The following are the materials chiefly employed in the production of generator gases:—Wood rubbish, pine nuts, waste of charcoal and coke, peat, brown coal, and mineral coal, but generally non-caking coal. Good coal is usually burnt directly on grates, and not converted into gas. It produces temperatures of upwards of 2000° C., and, owing to its compactness, it yields, in a fire-place of limited extension, in a given time, a considerable quantity of heat; and as coal pertinaciously retains its volatile substance, it gives off by distillation a regular current of gas, for which reason a too frequent stoking of the fire, which has a cooling action, must be avoided. The single pieces of coal lie compactly in the fire-place without leaving large interstices, and therefore induce a regular current of air; peat, wood, &c., behave differently. Wood produces a temperature of only about 1700° C.; it quickly gives off its volatile constituents, on account of its little compactness, and does not accumulate a great heating power in the fire-place, in consequence of which a more frequent stirring of the fire is necessary. The presence of an amount of water and many interstices exerts also an injurious effect on some kinds of fuel in the fire-place. This disadvantage can, however, be avoided for the most part when such fuel is converted into gas.

**State of Division of the Material.**—In converting compact fuel into combustible gas, it must be employed in a certain degree of division. Caking coal may be used in a pulverulent state, and non-bituminous coal in pieces measuring from ¼ to 2 cubic inches. Mineral coal to be converted into gas requires a much higher temperature than wood, peat, and brown coal, and its perfect conversion necessitates the use of blast under the grate. For the conversion of non-bituminous coal or anthracite into gas, the application of steam* has been recommended. Brown coal is best employed in pieces the size of an egg. Peat which has been cut in the form of bricks is used. Wood is usually employed in pieces from 6 to 10 inches long, having a section of ¼ square foot or more. The different kinds of fuel may, however, be advantageously employed in a finer state of division if the gas producers are suitably constructed.

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* Polyt. Centr., 1846, p. 942. Dingl., ciii., 289. Bgwkfd., viii., 505; x., 454. B. u. h. Ztg., 1849, p. 242.

Wood forms an excellent material for the production of gas, as it can be easily stored, contains a small proportion of ash, and admits of the process being conducted with great cleanliness; good turf approaches wood in its applicability, but requires large store-houses, and necessitates a frequent cleaning of the fire-place, if it contain a large proportion of ash; it also frequently requires a previous preparation. After turf, the purer kinds of brown coal are most applicable, then pure non-caking coal, and lastly, caking coal, which requires differently constructed generators.

The proportion of water and ash contained in the fuel, exerts an essential influence on the process of the conversion of compact fuel into gas.

**Proportion of Water.**—A large proportion of steam contained in the gases lowers their pyrometric heating power, and they can only be used with advantage after being liberated from it.

The fuel must be employed either in air-dried or in kiln-dried state, according to the temperature which the gases are intended to produce. Wood and peat must be, at least, air-dry, but it is better to employ them in a kiln-dried state; peat originally contains more water than wood, and is therefore more difficult to dry in the air as well as in kilns, as the piled-up wood leaves more interstices for the hot gases which pass through it. This difficulty in drying turf may be partly avoided by employing smaller kilns, or if it is dried in kilns as large as those used for wood, it is advisable to intermix wood with it, thus rendering it less compact. Peat containing not more than 6 per cent of ash, and being perfectly kiln-dried, not only yields a temperature equal to that of kiln-dried wood, but the quantity of both kinds of fuel required is also nearly equal. Brown coal, on being dried in kilns, is liable to disintegrate, and is, therefore, mostly used after being deprived of the greater part of its moisture by being stored for a long time in a covered and airy place. It has also been found advantageous to store fresh mineral coal under shelters for some time before using it.

**Ash contained in Fuel.**[*]—The difficulty of sustaining a regular current of gas increases with the amount of ash contained in the fuel, as the ash impedes the draught, and causes an irregular division of the current of air, especially if the ash cakes, which is generally the case when blast generators are employed, as undecomposed air will then enter the upper parts of the generator, and explosions may be apprehended. The removal of the ash causes the process to be interrupted. In order to avoid these interruptions, it is advisable to employ two generators of smaller dimensions, instead of one large one, and to clean them alternately.

Müller's grate, consisting of a perforated iron plate, admits of an easy removal of the ash. It has been recommended that some water should be kept below the grate for cooling the cinder and ash.

When blast generators have been employed, attempts have been made to add fluxes to the fuel, by which the ash would be converted into a fusible slag. The slag is then from time to time removed from the sole of the generator, through a tapping-hole, and a continuous process is thus obtained; on the other hand, it was found that the walling of the generator was too much attacked and wasted. The ash is sometimes removed in a manner similar to that with draught generators; the fuel above the tuyeres is suspended by iron bars thrust in for the purpose, and the ash below is removed. In order to keep the furnace as much as possible at the required temperature during the time in which the generator is cleaned, it is advisable to put some pieces of wood on the furnace hearth before the fire-bridge.

The gases produced in generators are generally purer than waste gases, although they frequently carry along with them dust (pulverulent fuel, ash); this is especially the case when the gases are produced in blast generators; this dust then collects and narrows the conduit pipes, and when used for puddling and re-heating iron, it deteriorates the metal and causes greater loss of it. On the other hand, it has also been observed that the dust diminishes the loss of iron, as it forms upon it an easily fusible slag, which protects the iron from oxidation.* The greater part of the dust may be retained by conducting the gases through a chamber previous to entering the furnace.

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[*] B. u. h. Ztg., 1857, pp. 23, 26. TUNNER'S LEOB. Jahrb., 1857, vi., p. 137 1860, p. 115.

**Construction of the Generators.**—Every reverberatory furnace can be simply and practically transformed into a gas furnace by placing the grate in a deeper position, and when clinker grates are employed, the advantage of heating the air of combustion is at the same time obtained. These gas furnaces with deeper lying grates can be re-constructed, at any time, into a common reverberatory furnace.

The generators are classified as draught and blast generators, according to whether the fuel is burnt in them by means of draught or blast. Draught generators were formerly employed for non-compact and easily combustible fuel, while blast generators were chiefly used for compact fuel and fuel of small division, as the latter, owing to its lying compactly, cannot be sufficiently penetrated by the draught. More recently, blast regulators have also been employed for all kinds of fuel, and they are stated to possess the following advantages :—

1. Perfect combustion of the small fuel, and no loss by pieces falling through the grate, as the latter can be either done away with altogether, or the grate bars can be placed so as to leave smaller interstices.

2. Quicker production of a larger quantity of gas.

3. Safer conduct of the production and combustion of the gas, as the admission of air is under better control than is the case in draught generators, and consequently fuel will be economised, and a higher temperature may be produced. The flame may be increased or diminished according to whether the upper blast, namely, that introduced on the furnace hearth, or the blast in the generator is prevailing, which may be arranged by simply turning a tap.

The following are some of the disadvantages of the blast generators:—The tuyeres frequently become obstructed, and the removal of ash and slag is inconvenient. When burning easily combustible fuel in large pieces, the blast is generally introduced somewhat above the sole of the generator through a wide tuyere, and several tuyeres issuing from a mutual reservoir are employed usually when treating compact or small fuel. The reservoir, or blast box, is provided at the back with openings corresponding with the tuyeres, through which the tuyeres can be cleaned. During the operation; these openings are closed with plugs. One side of the reservoir below the tuyeres is provided with an opening which may be closed, and which serves for the removal of the ash if the gas producer has no grate. This construction of the generator is advisable when fuel rich in ash or which easily disintegrates, is being treated, as in such case the grate will be soon obstructed. The blast is introduced into the generator with low pressure, and mostly in a cold state, in order to preserve the grate and the furnace wallings. Some Swedish gas reverberatory furnaces are, however, worked with hot blast, which is, at the same time, used for burning the gases.

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* Leob., Jahrb., 1860, p. 115.

An important part of a gas generator is the mouth for charging the fuel; this mouth must be constructed in such a manner that the atmosphere is prevented from entering the generator, and the combustible gases produced in it from escaping from it. If atmospheric air is allowed to enter, the formation of an explosive gas mixture will most likely be the consequence, or, at least, the normal proportion between gas and air will be modified, and consequently the gas will burn too soon, or the flame on the furnace hearth will contain a very variable surplus of air, so that the temperature will decrease.

There is less danger that gases will escape from a draught generator on its being charged, than that the atmospheric air will enter it, whilst, with blast generators, the contrary is the case.

The construction of various kinds of gas reverberatory furnaces is shown in Figs. 56, 57, 214—224, 257, and 258, of our second volume.

Siemens's regenerative furnace is shown in Figs. 245—248 of vol. ii., and in Figs. 41 and 42, and subsequent figures of the present volume.

This furnace received the distinction of the grand prize at the last Paris International Exhibition; it has been largely introduced both here and on the Continent, and its success in various branches of industry is everywhere established.*

M. F. Lundin,† of Munkfors, in Sweden, has made an improvement in the Siemens furnace; it consists in the injection of cold water into the gases before they enter the combustion chamber of the furnace, as by this means they are washed and purified, and the steam carried with them is also condensed. There is always a large proportion of steam contained in gases produced from fuel which has not been dried, and it amounts to 30 per cent by weight in the gases produced from saw-dust, which fuel has been successfully worked by M. Lundin for about two years. The other hurtful substances in the gases are solid matter carried along mechanically, and gaseous combinations which are absorbed by water, and of the latter combinations sulphurous acid is especially injurious; the application of Lundin's method, therefore admits, also, of the employment of those kinds of fuel that contain much sulphur. M. Lundin carries out his plan as follows:—The gases in their heated state pass from the generator through a pipe which leads into a chamber, where a series of jets of cold water are brought into contact with the gas. There, is, further, a pile of iron bars in that chamber, over which water is kept flowing constantly, for the purpose of keeping them cool, and through this the gases are made to pass in their ascent. After this the dried and purified gases pass off to the Siemens furnace in the usual way.

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* Berggeist, iv., No. 4 (1858). Polyt. Journ., xxxviii., Hft. 20, p. 174; Bd. 176, Hft. 1, 1865; April Hft., 1866. B. u. h. Ztg., No. 31, 1862; No. 31, 1864; No. 8, 1865; Nos. 28, 37, 1865; No. 21, 1866; No. 42, 1867. Polyt. Centr., 1865, 7 Lief. Neueste Erfindungen, No. 16, 1866.

† Köhn, Iron and Steel Manufacture, p. 141. Berggeist, No. 90, 1866. Polyt. Journ., April, May, 1867. B. u. h. Ztg., No. 19, 1867; Nos. 6, 21, 1868.

M. Köhn most justly observes that, with the employment of Siemens's furnace and M. Lundin's scientific addition to it, there is no improbability of a successful utilisation of peat for the purposes of iron and steel manufacture, and indeed for any other process requiring an intense heat.

Gases produced from wood,[*] peat,[†] brown coal,[‡] mineral coal,[‖] anthracite,[§] charcoal,[¶] and coke[**] are employed for various technical purposes.[††]

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[*] B. u. h. *Ztg.*, 1849, No. 6; 1851, p. 469; 1852, p. 610; 1855, pp. 93, 149; 1856, p. 98; 1857, p. 119. Ann. d. min., 4 sér. iii., 207.

[†] Bgwkfd., xiii., 39, 100; xvi., 430. B. u. h. Ztg., 1849, pp. 81, 364; 1857, pp. 26, 107, 119. Ann. d. min. 4 sér., iii., 207. Polyt. Centr., 1849, p. 364; 1854, p. 303. Tunner's Leob. Jahrb., 1860, p. 112.

[‡] Karst., Arch., 2 R., xxiii., 729. B. u. h. Ztg., 1844, pp. 53, 89, 92, 142, 184; 1845, p. 521. Bgwkfd., vii., 26; ix., 249; xi., 249, 309.

[‖] Karst., Arch., 2 R., xxiii., 729. B. u. h. Ztg., 1843, p. 611; 1857, p. 25. Bgwkfd., ix., 344, 521.

[§] Polyt. Centr., 1846, p. 492. Bgwkfd., viii., 505; x., 454. B. u. h. Ztg., 1849, p. 242; 1857, p. 32. Dingl., ciii., 289. Ann. d. min., 4 sér., xiii., 128.

[¶] B. u. h. Ztg., 1852, pp. 611, 627, 645; 1856, p. 99. Ann. d. min., 3 sér., iii., 207. Bgwkfd., xiii., 123.

[**] Ann. d. min., 4 sér., v., 79.

[††] Karst., Arch., 2 R., xvii., Hft. 2. Polyt. Centr., 1843, Hft. 11. Bgwkfd., vi., 296; vii., 33, 49, 465; ix., 344, 465, 480; x., 186; xi., 204; xii., 271, 462. B. u. h. Ztg., v., 817; vi., 225. Erdm., J. f. ök. u. Techn. Ch., v., 206. Jahrbuch f. d. sächs. Berg- u. Hüttenmann., 1849, p. 95.

# CHAPTER III.

## MATERIALS USED IN THE ERECTION OF FURNACES.

THE materials used in the building of furnaces must have the property of sustaining the temperature which the chemical process carried on in the furnace requires, without melting. They must undergo little or no modification from the chemical action of the atmosphere, the ores, and the flame, and they must resist the changes of temperature without cracking. The behaviour of the materials in higher temperature may be ascertained by experiments with the blowpipe, or in a draught furnace.*

In treating basic mixtures, building materials rich in bases (serpentine, for instance) are, if possible, chosen for constructing the furnaces, and materials rich in silica are employed for furnaces treating acid mixtures. But it is not alone the amount of silica and bases contained in the mixture that wastes the furnace walling; the same action, in a considerable degree, is produced by sulphides, and, in smelting them, those parts of the furnace which come into contact with the smelting mass are, therefore, provided with a sort of coating (small coal in admixture with loam, &c.) Refractory crucibles, for instance, are of excellent quality if they admit of repeated meltings of sulphide of iron.†

Those materials are the most refractory which consist only of one base and silica. The refractoriness decreases with the number of bases, especially if the materials contain a large amount of the protoxides of iron and manganese, lime, and alkalies.

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* Mitthl. des Gew.- Ver. f. d. K., Hannov., 1838, Lief. 17, p. 247; 1839, Lief. 20, p. 410.

† Berggeist, 1860; No. 7.

It is not always best, however, to employ the most refractory materials, as, on being heated, they may crack and fly off without melting, or they may be worked with too great difficulty. This is the reason why pure quartz is seldom used in the construction of furnaces, although it is highly refractory.

The chief materials are—native stones of various descriptions, artificially manufactured stones, and refractory masses for the formation of smelting hearths.

## A. NATIVE STONES OR ROCKS CONSISTING OF SILICA OR VERY REFRACTORY SILICATES OF ALUMINA.

The roughly cut stones, before being employed, are usually stored for a long time under shelter in a dry place, in order to deprive them of their natural moisture. Stratified rocks, sandstone, for instance, on being stored, are marked to show the position which nature assigned them, and, to prevent their lamination in the furnace, they are walled-in in their original bed position, so that one of the four transverse sides is turned towards the fire.

The following are some of these rocks:—

1. **Rocks Rich in Silica, such as Sandstones,** and especially those whose grains of quartz are cemented by a siliceous clay. The sandstones containing lime, iron, and bitumen are less refractory.

In many respects, argillaceous sandstone,* in which clay forms the cement, is superior to siliceous sandstone; this refers particularly to those cases in which a change of heat is inevitable. Clay does not form a strong cement, and such stones are generally found to be soft in the quarry, but harden on being exposed to the air or heat. These, however, do not generally resist high heat so well as siliceous sandstones, and when fluxes come into contact with them when hot, they are soon melted. Sandstones which contain spangles of mica, or particles of pyrites, or which are coloured by any metallic oxides, particularly protoxides, are not generally fire-proof; still there are instances in which such stones are used with advantage.

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* OVERMANN, Treatise on Metallurgy, p. 316.

In the selection of sandstones for hearth stones we must be guided chiefly by experience. Coarse-grained stone, such as millstone grit, which occurs in the lower strata of the coal measures, is generally found to be of good quality. The coarse sandstone in the higher strata of the coal formation is not often adapted to resist a strong heat and the influence of fluxes, because its cement consists chiefly of lime, clay, and iron. In these upper strata the fine-grained stone appears to be superior to the coarse grit. Transition or old red sandstone is generally found to be durable, particularly those kinds in which grains of white quartz of the size of peas or small beans are visible. Sandstone is peculiarly suited to serve as a refractory stone; it resists heat in a higher degree than almost any other, and if compact, is less attacked by fluxes than any other kind of rock. It is found almost everywhere in the United States, and is easily quarried and cut into the required forms.

Sandstone from the coal regions near Dortmund, in Westphalia, contains 88 parts of silica, 8 of ferruginous alumina, and 4 of manganese, lime, magnesia, and carbonaceous substances. Red sandstone from the neighbourhood of Schweinfurth contains from 92 to 99 per cent of siliceous substances. Sandstone from the Carpathian Mountains contains—

| | | |
|---|---|---|
| Quartz and clay . . . . . . . | 70 | per cent |
| Carbonate of lime . . . . . . | 18 | ,, |
| Carbonate of magnesia . . . . | 3 | ,, |
| Carbonate of iron . . . . . . | 10 | ,, |

Siliceous sandstones contain from 97·5 to 98·7 per cent of quartz sand.

Sandstone of the tertiary formation* (molasse sandstone from the Bavarian Alps) contains—

| | | |
|---|---|---|
| Silica. . . . . . . . . . . . | 28—75 | per cent |
| Carbonate of lime . . . . . . | 2—30 | ,, |
| Carbonate of iron and manganese | 3—56 | ,, |
| Alumina . . . . . . . . . | 1—1·5 | ,, |
| Bitumen . . . . . . . . . | 1—9 | ,, |

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* Bischoff's Geologie, ii., 1631.

Even if the sandstone is of good quality, it is expensive to work it into small pieces, whilst larger pieces, on being heated, have a tendency to fly off, and to assume the form of separate columns. The sandstones, for instance, that form the hearth of an iron blast furnace, when the furnace is blown out, appear frequently in prismatic separations similar to lava and anthracite, and, on striking them with a hammer, they fall asunder, forming pretty regular prisms, mostly with five sides, but prisms having three, four, and nine sides also occur.*

Hearth stones worked from sandstone, externally of good appearance, sometimes contain quartz, coal, or oxide of iron in their interior clefts and nests of clay. These run parallel with the fire side of the stone, and, in this case, flakes will come off from the stone when it is exposed to higher temperature. Sandstone usually expands but little on being heated; some kinds, however, swell considerably.

Many iron works in Sweden construct the hearths of their blast furnaces of a very good sandstone of the Silurian formation, occurring in the south of that country. This sandstone has great similarity to that of Salles, which is universally used in Bretagne (France) for the hearths of blast furnaces.†

**Kaolin Sandstone** is used in Thuringia‡ for constructing furnace hearths. In the iron works at the Upper Hartz the use of sandstones for constructing the hearth of blast furnaces is being gradually abandoned in favour of an artificial mass (vol. ii., p. 446).

An excellent material for this purpose is the *pudding-stone*|| from Huy, in Belgium, a coarse-grained conglomerate consisting of quartz rubbles, which are almost always of a white colour, and cemented by a white mass of quartz. This pudding-stone is used in the iron works of Belgium and of a part of France, and sometimes also in

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* Oesterr. Ztschr., 1857, p. 207. HAUSMANN, Molekularbewegungen, 1856, p. 11.

† B. u. h. Ztg., 1857, p. 126.

‡ Berggeist, 1860, No. 74, p. 606.

|| B. u. h. Ztg., 1859, p. 311.

Germany. White stones are preferred to those coloured by oxide of iron, and those composed of small rubbles to those containing large ones, as the latter become separated when the stones are transported. Owing to their great hardness, these stones are shaped with difficulty, and before the furnace is blown in, they require to be coated with refractory clay, as they are liable to crack and fly off on being heated quickly, but they last a long time after they have attained a higher temperature. They expand greatly by the action of heat, which fact must be taken into consideration in the construction of the furnace, and on account of their great hardness, they cannot be employed in small pieces. The pudding-stones are also more liable to fly off in flakes than artificial stones which have been carefully manufactured.

**Quartz Slate** consists of a fine-grained and sometimes compact mass of quartz, which is separated into layers by spangles of mica.

2. **Talcose Rocks**, such as talc slate, chlorite slate, serpentine, and soapstone; they are more or less fire-proof, according to their proportion of other bases, chiefly oxide of iron. They may be easily shaped, especially the finely laminated slates; talc slate is more refractory than chlorite slate.

The *talcose* or *talc slate* is laminar or scaly talc, frequently mixed with quartz and felspar; it contains—

| | | |
|---|---|---|
| Silica . . . . . . . | 50—64 | per cent |
| Magnesia . . . . . . | 25—34 | ,, |
| Peroxide of iron . . . | 0·5— 9 | ,, |
| Alumina . . . . . . | 0— 7 | ,, |

This substance[*] often forms a very durable fire-proof stone, particularly when the slate has been exposed to a strong, hardening heat, in the native rock. This kind of slate is found along the Atlantic coast; it forms soapstone when soft, but in that variety which is cemented by heat, it is extremely hard. The latter quality occurs frequently in the Southern States, and the former in Maryland, Pennsylvania, New Jersey, and all the New England States. This substance is extensively used in puddling furnaces, for which it is peculiarly adapted by the resistance that it offers to the influence of the oxides of metals.

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[*] OVERMANN's Treatise on Metallurgy, p. 319.

**Chlorite Slate** is a mass of chlorite frequently intermixed with quartz or felspar, and also with spangles of mica and talc. It contains:—

| | | |
|---|---|---|
| Silica | 26—31 | per cent |
| Alumina | 5—22 | „ |
| Magnesia | 15—42 | „ |
| Peroxide of iron | 10—27 | „ |
| Water | 9—12 | „ |

**Serpentine**, on account of its small amount of silica, is well adapted for the construction of furnaces intended for the smelting of mixtures rich in bases; it contains, on an average:—

| | | |
|---|---|---|
| Silica | 44 | per cent |
| Magnesia | 43 | „ |
| Water | 13 | „ |

Part of the magnesia (10 per cent) is sometimes replaced by oxide of iron.

The hearths of some blast furnaces in Styria are constructed of serpentine-rock, others of sandstone, and others, again, of a mass consisting of clay and powdered serpentine; this mass is used up to the boshes, and the shaft-lining is made of plates of talc slate, and of bricks of magnesite. Sandstone is, however, preferred to serpentine if a mixture rich in silica is smelted, and a higher temperature required for the production of grey pig-iron.

**Soapstone** is a combination of mono- and bi-silicate of magnesia, containing:—

| | | |
|---|---|---|
| Silica | 63 | per cent |
| Magnesia | 32 | „ |
| Water | 5 | „ |

The magnesia is sometimes replaced by protoxide of iron to the amount of 6 per cent.

3. **Argillaceous Rocks**, such as **Clay Slate** and **Greywacke**; they are less refractory than the preceding rocks, on account of the amount of lime, alkalies, and protoxide of iron which they contain. Their composition is as follows:—

| | | |
|---|---|---|
| Silica | 44—79 | per cent |
| Alumina | 10—36 | ,, |
| Protoxide of iron | 5—16 | ,, |
| Lime | 2—16 | ,, |
| Magnesia | 0·5— 4 | ,, |
| Potash | 1— 7 | ,, |
| Soda | 0·04— 2 | ,, |
| Water | 1— 7 | ,, |

The lead and copper smelting furnaces of the Lower Hartz are built of clay slate. The clay slate from the Upper Hartz* is more easily fusible than bricks made of common loam.

4. **Granite, Gneiss, and Mica Slate.**—Granite has the following composition :—

| | | |
|---|---|---|
| Silica | 63—76 | per cent |
| Alumina<br>Peroxide of iron | 14—30 | ,, |
| Lime | 0·5— 9 | ,, |
| Magnesia and alkalies | 0—15 | ,, |

Mica slate is composed as follows :—

| | | |
|---|---|---|
| Silica | 49—81 | per cent |
| Alumina | 1—26 | ,, |
| Peroxide of iron | 1—19 | ,, |
| Lime | 0— 5 | ,, |
| Magnesia | trace—11 | ,, |
| Potash | 0·5— 6 | ,, |
| Soda | 0·1— 3 | ,, |

Gneiss is used at Schmöllnitz in the construction of reverberatory furnaces. It can be easily dressed to the desired forms, and offers a strong resistance to high temperatures, and also to the sudden changes of heat. When heated slowly, it swells but little, and it does not laminate.

5. **Limestone** is not often employed.

The composition of limestone, as well as of sandstone, clay slate, mica slate, talc slate, gneiss, and granite, varies in different localities, and often, indeed, in the small compass of a quarry.

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* Kerl, Oberh. Hüttenprocesse, p. 271.

## B. ARTIFICIAL STONES—FIRE-BRICKS.

These stones are made of fire-clay. The term clay is applied to hydrous silicates of alumina, derived, for the most part, from the decomposition of felspathic rocks, and which are generally rendered impure by the admixture of other substances. These substances are—free silica, undecomposed silicates with or without alkalies, carbonate of lime, hydrous protoxide of iron, &c., and it is on their account that the composition of clays is in many cases so difficult to ascertain. Even chemical analysis is not always sufficient for judging of the applicability of clay to any desired purpose. The analysis shows the amount of substances which render the clay less refractory, but a clay perfectly free from such substances may still be useless for some purposes, if, for instance, it cracks on heating, contracts strongly, &c. This behaviour is probably based on the variable mixture of different silicates of alumina, and on the presence of more or less free silica, in different states of aggregation. Under such circumstances, there is nothing left but to submit the clay to high temperature, thus ascertaining its behaviour.

The refractoriness of clay is impaired by the presence of protoxide of iron and manganese, as well as of lime and alkalies. 3 or 4 per cent of oxide of iron does not exert any very considerable influence, not nearly so much as does an equal amount of alkalies. If the clay, on burning, assumes a yellow, and not a red, colour, its proportion of iron is not dangerous. An amount of undecomposed felspar present in clay, may be very injurious; it is therefore advisable to elutriate a sample of the clay and to examine the residue minutely.

The durability of the fire-bricks depends partly on the composition of the clay, but also to a great extent on the manner in which they are manufactured, on the compactness of the mass, the degree of baking, &c. The greater or less compactness of the fire-bricks, and the degree to which they are burnt, exert an influence on the resistance which they offer to sudden changes of temperature, and their refractoriness is influenced by their porosity and proportion of silica.

The plasticity of the clay increases with the amount of hydrated alumina that it contains.

**Fire Clays, 1.**—In this country,[*] the geological position of fire clay is immediately beneath coal, each bed of which rests upon a stratum, of greater or less thickness, of a clay possessing the peculiar qualities of fire-clay, and distinguished in the mining districts by the name of *under clay*, from the position it occupies with reference to coal. Stourbridge clay is of this character; the bricks manufactured both at that town and at Garnkirk are of very superior quality.

These English and Scotch clays, when ground and kneaded with water, are but slightly plastic; they become harder when dried, and when strongly burnt, they become very hard without caking.

The china clay, from Cornwall, is obtained by elutriation of decayed granite.

*Analyses of English and Scotch Clays.*

| | *a.* | *b.* | *c.* | *d.* |
|---|---|---|---|---|
| Silica | 63·7 | 46·1 | 45·25 | 69·99 |
| Alumina | 20·7 | 38·8 | 28·27 | 19·05 |
| Lime | — | — | 0·47 | — |
| Peroxide of iron | 4·0 | — | 7·72 | 2·70 |
| Water | 10·3 | 12·8 | 17·34 | 6·80 |
| Organic substances | | | — | — |
| Carbon | — | 1·5 | — | — |

| | *e.* | *f.* | *g.* |
|---|---|---|---|
| Silica | 42·0 | 47·5—83·3 | 59·49 |
| Alumina | 40·9 | 8·1—31·3 | 28·95 |
| Magnesia | 0·1 | trace— 3·0 | — |
| Lime | 1·3 | | trace |
| Protoxide of iron | trace | 1·8— 9·1 | 1·05 |
| Water | 14·7 | 3·6—12·3 | 11·05 |
| Organic substances | | | — |

*a—d*, clay from Stourbridge, analysed by Berthier, Le Play, Salvetat, and Heeren. *e*, clay from Stannington, by Le Play; less fire-proof than *a* *f*, clay from the neighbourhood of Newcastle-on-Tyne, by Richardson. *g*, clay from the iron works at Gartsherrie, by Schwarz.

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[*] URE'S Dictionary of Arts and Mines, vol. i., p. 735.

2. The materials requisite for the manufacture of good fire-brick are very abundant in the United States.* Between the Alleghany Mountains and the shores of the Atlantic Ocean there is a great deal of fire-clay; kaolin also, the result of the decomposition of felspathic rocks, is very common in these regions, and more abundant in the Southern than in the Eastern and Northern States. In the region of the western coal deposits, an abundance of slaty clay of good quality is found in the lower strata of the formation, of which, in Western Pennsylvania, first-rate fire-bricks are manufactured. In the higher strata of the coal basin, similar veins of clay are found, but these are of an inferior quality, and offer less resistance to fire than the former kind. Fire-clay, in one form or another, abounds also in all the Western States, and no doubt can be entertained of its being found in profusion on the western side of the Rocky Mountains.

3. The clays of Belgium† occur chiefly in the coal regions in the neighbourhood of Andenne; they are plastic, free from coarse sand, and, on burning, assume a yellowish colour; they also require for their full contraction a less high temperature than Scotch clay. The best kinds, occurring at Tahier and Mazet, are nearly free from iron; on being burnt they become greyish or remain white, and attain great hardness; clay of second quality occurs at Maizeroul, Haltinne, and Andenne; it is less plastic, and attains a yellowish red colour, on account of the larger proportion of iron which it contains.

*Analyses of Belgian Clays, by Coste.*

| | Tahier. | Mazet. | Maizeroul. | Haltinne. | Namur. |
|---|---|---|---|---|---|
| Silica | 56·0 | 52·0 | 46·0 | 40·0 | 71·79 |
| Alumina | 26·0 | 25·0 | 33·4 | 25·0 | 19·49 |
| Magnesia | 2·0 | trace | 1·0 | 1·6 | 0·06 |
| Peroxide of iron | — | — | — | 0·4 | 0·85 |
| Alkalies | — | — | — | — | 0·85 |
| Water | 14·0 | 12·6 | 18·6 | 15·0 | 7·47 |
| Sand | 2·0 | 9·8 | 1·0 | 18·0 | 0·85 |

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* Overmann's Treatise on Metallurgy, p. 326.

† B. u. h. Ztg., 1859, pp. 312, 405. Berggeist, 1859, No. 40.

Belgian clay is sold in oblong lumps, each weighing 40 or 50 lbs.; the price on board ship on the Rhine is about 40 thalers, or £6, per 10,400 lbs. Prussian.

4. **Rhenish Clays*** from Vallendar, near Coblenz, and Mehlem near Königswinter, are very plastic, and frequently nearly free from iron; in many instances they can replace the English and Scotch clays; this, however, has not been the case in the manufacture of the vessels used for distilling zinc.

*Analyses of Rhenish Clay.*

| | Vallendar. | Mehlem. |
|---|---|---|
| Silica | 55·46 | 77·32 |
| Alumina | 31·74 | 15·57 |
| Peroxide of iron | 0·59 | 0·86 |
| Lime | 0·19 | trace |
| Magnesia | 0·14 | 0·13 |
| Potash | 2·49 | 0·67 |
| Soda | 0·68 | 0·63 |
| Water | 9·37 | 5·61 |

5. The clay from Passau† is usually mixed with graphite and worked into crucibles (Ypser crucibles).

The following analyses show its composition:—

| Analysed by | Berthier. | Forchhammer. | Fuchs. | Salvetat. | Leschen. |
|---|---|---|---|---|---|
| Silica | 42·4 | 43·30 | 43·65 | 45·79 | 42·4 |
| Alumina | 57·6 | 33·56 | 35·93 | 28·10 | 57·6 |
| Lime | — | 2·59 | 0·88 | 2·00 | — |
| Peroxide of iron | 0·7 | | 1·00 | 6·55 | 0·7 |
| Water | — | 16·44 | 18·00 | 17·00 | — |

6. Clay occurring in Hesse,‡ in Almerode, for instance, makes excellent crucibles, and has the following composition:—

| | Berthier. | Salvetat. |
|---|---|---|
| Silica | 46·5 | 47·50 |
| Alumina | 34·9 | 34·37 |
| Magnesia | — | 1·00 |
| Lime | — | 0·50 |
| Peroxide of iron | 3·0 | 1·24 |
| Water | 15·3 | 14·43 |

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* B. u. h. Ztg., 1859, pp. 312, 405. Berggeist, 1859, Nos. 34, 71; 1860, No. 47.

† Berthier, met. analyt. Ch., i., 64. Polyt. Centr., 1854, p. 1444.

‡ Erdm. J. f. pr. Ch., iv., 493. Erdm., J. f. ök. Ch., xviii., 125.

Clay from Krumnussbaum,* on the Donau, is stated to be still more durable for bricks and crucibles than Hessian clay. Sulphide of iron melted for six hours in crucibles formed of this clay, in Sefström's furnace, did not cause any waste in them, while Hessian crucibles were much corroded.

7. Clay occurring at Schöningen,† near Uslar (Hanover), is similar in its behaviour to English clay, and has, according to Streng, the following composition :—

| | |
|---|---|
| Silica | 59·01 |
| Alumina | 24·26 |
| Magnesia | 0·72 |
| Lime | 1·32 |
| Peroxide of iron | 4·04 |
| Alkalies | 1·20 |
| Water | 10·24 |

8. Clay occuring in the triassic formation at Kipfendorf‡ (Saxe-Coburg) approaches in quality the clays of Newcastle and Namur; it is worked in admixture with one or two parts of burnt clay and quartz sand. According to Fresenius, the clay is composed thus :—

| | | |
|---|---|---|
| Silica | 60·40 | 54·06 |
| Alumina | 24·09 | 26·99 |
| Peroxide of iron | 3·70 | 2·73 |
| Lime | 0·55 | 0·85 |
| Magnesia | 0·61 | 0·82 |
| Potash | 0·29 | 0·24 |
| Soda | 0·22 | 0·33 |
| Water and organic substances | 10·60 | 14·15 |

**Admixtures for the Clay.**—As most kinds of fire-clay strongly contract and crack when the bricks made of it are dried and baked, it is previously mixed with refractory substances, which, without reacting chemically upon the clay, expand or contract but little on being heated, and do not diminish in too great a degree the plasticity of the clay.

Such admixtures are :—

*a.* **Coarse Sand and Grains of Quartz.**—The latter are obtained by burning, pounding or rolling, and sifting the quartz. The grains must not be too small (the size of a pea or bean), as otherwise, at high temperature, the silica will react chemically upon the clay and impair its refractoriness. Grains of quartz impair the plasticity of clay more than sand.

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* Berggeist, 1860, No. 7.

† Mittheil. des. Han. Gew.-Ver., 1838, p. 242 ; 1839, pp. 410, 353.

‡ Berggeist, 1860, No. 74, p. 606.

Burnt and pounded clay behaves similarly to quartz, but at high temperature its chemical reaction upon the clay is less than that of quartz and sand.

The clay of which the Hessian crucibles are made contains one-third or one-half of its weight of fine sharp quartz sand. The Belgian fire-bricks are composed of one part by volume of raw clay and two parts of burnt clay.

Good fire-bricks combine great hardness and strength; they also possess a tenacity which prevents them from cracking in sudden changes of temperature, and when used for masonry, they form a uniform mass, which, at a corresponding temperature, gradually melts off.

*Analyses of Refractory (Fire-proof) Mass or Composition.*

| | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|
| Silica . . . . . . | 54·63 | 47·98 | 71·0 | 70·9 | 85·00 |
| Alumina . . . . | 40·27 | 46·94 | 23·0 | 24·8 | 11·33 |
| Magnesia . . . . | 1·03 | — | — | — | — |
| Lime . . . . . . | 1·53 | 2·32 | — | — | — |
| Peroxide of iron . . | 2·67 | 2·94 | 4·0 | 3·8 | 2·23 |

1. English fire-brick, analysed by Fresenius. 2. The burnt clay contained in the fire-brick. 3. English crucible, by Berthier. 4. Hessian crucible, by Berthier. 5. Fire-brick made of kaolin, occurring at Halle, by Wackenroder.

*b.* **Carbonaceous Substances**, such as graphite, coke, charcoal, &c. These substances are especially adapted, as they are perfectly fire-proof and without chemical action. They are used less in admixture with the clay for fire-bricks than with that for crucibles, as the latter are chiefly employed for melting metals, alloys, and cast-steel.*

Graphite is not consumed by the ordinary fire to which crucibles are exposed, and this behaviour makes it preferable to any other carbonaceous substances.

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* Erdm., J. f. ök. Ch., ii., 108, 299; xiii., 363. B. u. h. Ztg., 1845, p. 433. Oesterr. Ztschr., 1856, p. 245.

The crucibles made at Passau consist of one part of plastic clay (analysis on page 561) and three or four parts of graphite, occurring in that neighbourhood in gneiss, in the form of nests, layers and veins. It contains, according to Berthier, the following components:—

| | |
|---|---|
| Carbon | 34 |
| Silica | 41 |
| Alumina | 15 |
| Peroxide of iron | 8 |
| Magnesia and water | 2 |

It is necessary that the graphite employed should be as free as possible from substances (peroxide of iron, lime, &c.,) which impair the refractoriness of the clay. On a small scale, the graphite may be freed from these substances by heating it with two parts in volume of potash or soda, and by treating the residue with dilute acids.*

Coke and charcoal are likewise used as admixtures to the clay, but only in smaller quantities. An excess of these substances renders the clay friable and porous, and the carbon contained in them is more easily combustible than that contained in graphite. The crucibles used at Uslar (Hanover) for melting steel are made of a mixture consisting of 9 parts raw clay from Schöningen (page 562), 14 parts of burnt clay, and 6 parts of charcoal.

*c.* The clay is sometimes also mixed with very refractory minerals, such as halloisite† ($Al_2O_3$, $SiO_3$ + $Al_2O_3$, HO), magnesite in burnt and pounded state (magnesite bricks are employed in Styria in the construction of blast and puddling furnaces), serpentine (Styria), &c.

## C. ARTIFICIAL STONES OF LESS REFRACTORINESS.

1. **Common Bricks**‡ made of clay (loam) containing lime, peroxide of iron, and alkalies. Unbaked bricks, made of pounded clay slate,|| are sometimes employed at the smelting

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* Polyt. Centr., 1855, p. 1404. Oesterr. Ztschr., 1855, p. 355.

† B. u. h. Ztg., 1860, p. 394.

‡ Polyt. Centr., 1847, p. 1301.

|| Kerl, Oberh. Hüttenpr., 1860, p. 270. Dingl., cxiii., 133. Polyt. Centr., 1847, p. 1301.

works in the Upper Hartz; these bricks are then baked or burnt in the smelting process itself. Bricks which, on baking, have commenced to melt,* are well adapted for roasting apparatus, but less so for smelting furnaces, as they are liable to crack when exposed to higher temperature.

2. **Bricks made of Slag.**—Highly silicated viscous slags are sometimes formed into bricks in suitable moulds, and these bricks are employed for constructing those parts of the furnaces in which very high degrees of temperature are not produced. Bricks of this kind, made of slag which has resulted from lead smelting furnaces, are used at the Upper Hartz† for the construction of cupola furnaces for smelting lead ores and lead matt. The shaft of some Swedish iron blast furnaces‡ treating easily fusible ores is also partially constructed of bricks made of slag, with the exception of the upper part of the shaft, which is most strongly attacked by the frequent changes of temperature.

## D. RAW CLAY MIXED WITH QUARTZ OR BURNT CLAY.

This mixture is termed the *mass*, and is frequently employed in the construction of the hearth or the boshes, and indeed of both, in the iron blast furnaces of France, Sweden,‖ Silesia,§ Hartz,¶ &c. Although in the construction of a furnace hearth by means of "mass," more time is required than when stones are employed, the use of this mixture is frequently very advantageous in an economical point of view.

The "mass" is composed of the constituents of the firebricks, with this difference, viz., that the burnt clay or quartz is sometimes employed in larger pieces of the size of a nut, in order to prevent, as much as possible, the contraction of the mass.

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* Berlin. Handel's Industrie- und Gewerbeblätter, iv., 205.

† KERL, Oberh. Hüttenpr., 1860, p. 273.

‡ B. u. h. Ztg., 1857., p. 127.

‖ TUNNER, Eisenhüttenwesen in Schweden, 1858, p. 31.

§ KARST., Arch., 1 R., ii., 176. B. u. h. Ztg., 1160, p. 393.

¶ CARNALL'S Preuss. Ztschr., ii. Bd., 3 Lief., p. 126 (1854).

The mass employed in the Swedish Iron Works is composed of raw fire-clay and burnt and powdered quartz; the division of the quartz varies from the finest sand to the size of a pea; the composition used for the lower parts of the furnace hearth contains one-tenth or one-eighth of powdered clay, and nine-tenths or seven-eighths of quartz, while that for the upper parts is composed of a quarter or one-third of pounded clay, and three quarters or two-thirds of quartz.

The mass used for constructing the furnace hearth at Gittelde in the Hartz, contains four parts by volume of quartz, and one part of clay, that is for constructing those parts of the hearth walling which face the inside of the furnace, whilst the mass joining the rough walling of the furnace consists of five parts by volume of quartz, and one part of clay. The quartz used in the mixture has the following composition:—

| | |
|---|---|
| Silica | 93·85 |
| Peroxide of iron | 2·15 |
| Alumina | 1·55 |
| Per- and protoxide of manganese | 1·80 |
| Lime | 0·92 |
| Magnesia | 0·41 |

The clay employed contains:—

| | |
|---|---|
| Silicate of alumina | 95·0 |
| Carbonates of lime and magnesia | 1·0 |
| Protoxides of iron and manganese | 1·3 |
| Water | 2·4 |

In smelting iron ore mixtures rich in silica, Weniger* recommends a mixture of four parts of pure quartz sand from the size of millet up to that of a pigeon's egg, one part of fire-clay, and one part of old mass, or of coarsely pounded fire-bricks, and a mass composed of one part pure raw clay, one part of quartz sand, and four parts of burnt clay when smelting ore mixtures containing a prevailing amount of alumina.

The roofs of the distilling furnaces in the zinc works of Upper Silesia† are always constructed of a mass composed of one part of Polonian clay and two parts of sand; the fire-places are sometimes built in the same manner.

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* WENIGER, pract. Schmelzmeister, p. 89.

† KERL, in MUSPRATT-STOHMANN'S tech. Chem., iii., 1900.

The hearth of the blast furnace (Friedauhohofen) near Vordernberg, is constructed of mass composed of four parts of powdered serpentine and one part of fire clay.

In preparing the "*mass*," the components are mixed either in a dry state, and then wetted to such a degree that on being strongly pressed they will form balls, or the clay is stirred with hot water, so as to form a paste, which is thrown on the pounded quartz, and mixed with it. The mixture is not sticky and rather dry, and in forming the hearth or furnace-part, for which the mixture is intended, it is stamped into thin layers with warmed pounders after the surface of the previous layer has been made rough.

## Fire-Proof Cement.

Fire-proof stones are frequently joined together without any cement being employed, as it is sufficient to put the well dressed stones into their places, or to grind them one upon another. When cement is required, good loam or clay may be employed, if the walling is not exposed to high temperatures. Fire-proof cement is best prepared of a mass which has a composition similar to that of the fire-bricks, except that it is kept somewhat more plastic and of thinner consistency.

A suitable mass of this kind is a mixture of one part of finely sifted quartz sand, two parts of old pounded mass, used in the construction of furnace hearths, and one part of clay. Weniger recommends that the tuyeres, before being put into their places in the furnace walling, should be coated with a mixture of clay, pounded plumbago crucibles, and fine sand, or a compound of fresh graphite and pounded clay crucibles; this mixture is then formed into a paste by the addition of clay water.

If cement is employed, the bricks are plunged into it, and the superabundant cement is allowed to flow off. To protect the stones against the direct action of the fire, they are brushed with a glazing mass, consisting of three parts of dry loam and one part of common salt, which is formed into a thin paste by being mixed with weak vinegar.

Lime mortar is not employed, as a high temperature does not harden it; gypsum mortar easily fuses.

**Refractory Loose Masses for the Formation of Smelting Hearths.**—The smelting, &c., of ores, is seldom directly effected on the refractory stones of the walling, as is the case in iron blast furnaces, in roasting-reverberatory furnaces, &c.; the refractory stones which form the sole of the furnace are, moreover, provided with a special cover. This cover must have the property of not becoming fluid or of cracking, at the temperature which the process requires, besides which it must react as little as possible upon the smelting mass.

The following substances answer the purpose more or less efficiently:—

1. **Brasque** or **Gestübbe**, that is to say charcoal, coke, graphite, or anthracite powder mixed with clay (loam) or clay slate. Charcoal powder and clay are mixed in variable proportions, according to the purpose for which it is intended. One kind consists of equal parts of both substances, another has a prevailing amount of clay, and in a third there is a large proportion of charcoal powder. The latter kind resists the influence of sulphides better than Gestübbe rich in clay, but it wastes more both by mechanical means and by combustion. An addition of marl, sand, or pounded sandstone, renders the brasque more refractory. Coke and anthracite when present in a smaller quantity than charcoal, render the hearth more durable than the latter fuel. The brasque formerly used at the smelting works in Freiberg, consisted of equal parts of small charcoal and loam, it is now replaced by a mixture consisting of two parts of powdered coke and one part of loam. At the lead and silver smelting works on the Upper Hartz, the brasque employed for most processes is composed of one part of powdered clay slate, and two of small charcoal; equal parts of these substances are employed in the process of reducing litharge. The brasque commonly used in the Lower Hartz consists of equal parts of small charcoal and loam; when black copper is submitted to an

oxidising smelting in reverberatory furnaces, two parts of it are mixed with one part of marl, and in refining copper on a small hearth some sand is added to the brasque. In the copper smelting furnaces at Boston,[*] the Gestübbe consists of equal parts of quartz sand, clay, and anthracite.

It protects the furnace walling from the attack of the liquid slag; it facilitates the removal of deposits, being a bad conductor of heat; it concentrates the temperature, and, on account of its carbon, it has reducing properties, and will, of course, gradually waste, but it is easily renewed.

The preparation of this mixture is effected by pounding or otherwise mixing the sifted substances, and afterwards wetting them with just sufficient water to cause them to form balls on being pressed.

2. **Clay, Clay Slate, and Loam,** in a moist state, are sometimes employed by themselves when an admixture of coal is not admissible. Hearths, &c., formed of these materials are liable to crack, and require to be warmed very carefully (smelting of lead ores in reverberatory furnaces). The hearth sole of the reverberatory furnaces at Schmöllnitz, used for fining copper, is composed of 50 per cent of quartzose clay slate, 33 per cent of talcose slate, and 17 per cent of a mass suitable for the manufacture of common bricks.

3. **Quartz Sand** is chiefly employed in the reverberatory furnaces which are used for smelting copper. The sand employed at the copper works of South Wales, has, according to Le Play, the following composition:—

| | |
|---|---|
| $SiO_3$ | 86·0 |
| $CaO$ | 5·7 |
| $MgO$ | 0·8 |
| $Al_2O_3$ | 1·6 |
| $Fe_2O_3$ | 1·2 |
| $CO_2$ | 4·5 |
| $HO$ | trace |

The sole of the cupola furnaces used at Dillenburg for smelting nickeliferous pyrites is covered with pounded fire-proof sandstone.

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[*] B. u. h. Ztg., 1859. p. 324.

4. **Slag** is employed for forming the hearth of puddling furnaces.

5. **Lixiviated Wood Ash rich in Lime*** was formerly in very general use for the formation of the hearths of lead cupelling furnaces. At the present time, however, this material is mostly replaced by marl, which, owing to its uniform quality, enables the process to be conducted with greater security. It imbibes less oxide of lead and silver on account of its greater compactness, and admits, therefore, of a greater yield of these metals. The chief components of lixiviated wood ash are caustic lime, carbonate of lime, and magnesia, combined with phosphoric acid, silica, and carbonic acid. If the wood ash contains too much alumina, the hearth is liable to crack.

Admixed carbonaceous components must be removed by a previous heating. The ash of beech wood forms the best material for the construction of hearths.

Wood ash suitable for the construction of hearths of cupelling furnaces, consists of—

| | | |
|---|---|---|
| Carbonate and caustic lime. | 66—70 | per cent |
| Silica . . . . . . . . . | 17—21 | „ |
| Alumina . . . . . . . . | 10—11 | „ |
| Peroxide of iron . . . . | 2— 4 | „ |

6. **Marl** is essentially carbonate of lime intermixed with clay and sand in variable proportions; it is, therefore, classified into lime, clay, and sand marl, according to the component which predominates.

Marl was employed in lead cupelling furnaces in Tajowa (Hungary) as far back as the years 1803 and 1804. It was used at Przibram in 1806; at Tarnowitz in 1813; at Freiberg in 1815; in the Lower Hartz in 1828; and some years later, in the lead works of the Upper Hartz.

Good marl used at the latter place has the following properties:—Large pieces of it, on exposure to the air, disintegrate, and fall into pieces of the shape of a parallelopiped. It has a conchoidal fracture, is smooth to the touch, sticks slightly to the tongue, and when exposed to the atmosphere for a long time, its surface has a black or yellow colour. Its composition is as follows :—

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* Kerl, Oberh. Hüttenprocesse, 1860, p. 285. Erdm., J. f. pr. Ch., lxiii., 51.

| | | |
|---|---|---|
| $SiO_3$ | 21·22—22·24 | per cent |
| $Al_2O_3$ | 5·39— 6·76 | ,, |
| $Fe_2O_3$ | 3·54— 5·39 | ,, |
| $CaO, CO_2$ | 65·65—66·41 | ,, |
| $MgO, CO_2$ | 1·05— 2·22 | ,, |

Marl containing a large amount of alumina causes the hearths to crack, and those hearths in which a large amount of lime prevails have little consistency, besides which, they evolve a great deal of carbonic acid, thus becoming blebby. Native marl may frequently be improved by mixing the various kinds of it, or by an addition of clay or lime; marl may also be produced artificially by mixing three or four parts by volume of lime with one part of clay. Before being used, the marl is pounded, sifted, and uniformly wetted with just so much water, that, when pressed by the hand, it forms a ball without giving off any moisture.

7. **Bone Ash** is usually employed for the formation of hearths in English cupelling furnaces, furnaces for fining silver, &c. It is obtained by burning, crushing, and elutriating bones. Its chief components are phosphate and carbonate of lime in unequal proportions, with which small quantities of phosphate of magnesia, sulphate of soda, fluoride of calcium, &c., are intermixed.

# SUPPLEMENT.

# SUPPLEMENT.

THE following supplementary chapter contains theoretical and practical papers on metallurgical subjects, which have been published since the foregoing was written. It has been thought advisable to reproduce them here, as they elucidate the present state of metallurgical science.

## THE CHEMISTRY OF THE BLAST FURNACE.

### By I. LOWTHIAN BELL.*

On being honoured by the President and Council of this Society to deliver to its members an address on some branch of applied chemistry, I have selected the blast furnace as a subject replete with interest, and in the hope that the opportunities I have enjoyed for many years as an iron manufacturer may justify the choice I have made.

The ground to be gone over has, it is true, been already travelled by many distinguished chemists during the last forty years, but possibly it may interest those whom I have the honour of addressing, to hear how far the experience of a practical smelter accords with the views of scientific men, whose means of observation have necessarily been more limited in their duration and character than his own.

All present have probably witnessed the various operations carried on in connection with the smelting of iron in a blast furnace. Into the throat of a great building large barrows of rough-looking materials are shot by powerful men. At the lower portion of the edifice, matters are conducted upon a scale of corresponding rudeness. At three sides a roaring blast is being poured into the furnace, while from the fourth, running almost incessantly, is a current of highly heated slag, which is dealt with in the roughest of fashions.

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* The Journal of the Chemical Society, June, 1869.

Generally without any protection from the weather, the "keeper" is occupied in moulding his "pigs" in coarse sand, or in maintaining his blast-pipes free from all obstruction, until the time arrives, when, by mighty blows, he drives in the tapping bar in order to afford an exit for the molten iron destined to fill the rude spaces prepared for its reception.

When everything seems forced into obedience by intense heat or violent exertion, there is, one might think, nothing left for milder treatment to accomplish; yet notwithstanding all appearance to the contrary, there are few chemical processes requiring for their proper operation greater nicety, or where perfect success is contained within narrower limits than the smelting of iron.

In a few words, I may remind you that the ends sought to be accomplished in the blast furnace are the deoxidation of the peroxide of iron, which is the usual form of combination in which the metal is delivered to the smelter, its carburisation and fusion; accompanying this is the expulsion of carbonic acid from the limestone, and the union of the lime it contains with the earthy matters associated with the ore and fuel to form a fusible slag.

In this brief description the fuel employed is supposed to be coke or charcoal; for should raw coal be used, the hydrocarbons and other volatile constituents emitted on the application of heat may be left out, as forming no necessary part of the process we are about to consider.

The circumstances of the different stages of the operation to which allusion has just been made, being effected at different temperatures, has led some chemists to divide the interior of the blast furnace into a certain number of spaces or regions, and designate them according to the character of the action which was supposed to be carried on therein. Scheerer, among others, assigns a distinct zone, in which he imagines that each of the various steps of the process of smelting is more or less effected. The uppermost one he calls the warming zone, in which the ascending current of gases imparts a portion of its heat to the materials just entering the furnace; the second is the reducing zone, where the oxide of iron begins to part with its oxygen, and in which also the carbonic acid of the limestone is expelled; in the third, carbon is supposed to unite with the iron, which, along with the earthy constituents of the materials, is melted in the fourth or zone of fusion, by means of the intense heat given off immediately below in the fifth, or zone of combustion. It is into the last zone that the blast is admitted, the oxygen of which is almost instantaneously converted into carbonic acid, which gas, coming in contact with incandescent coke or charcoal, as the case may be, generates carbonic oxide to serve as the reducing agent in the upper portion of the furnace.

The annexed figure will convey an idea of the manner in which Scheerer conceived the interior of a furnace was divided, and the space he allotted to each division of the operation, and alongside of it is placed a diagram indicating the supposed increase of temperature.

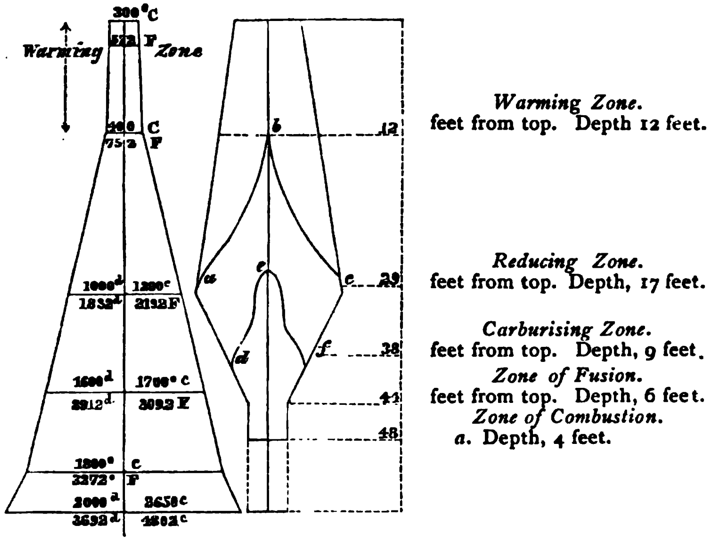
More recently Professor Tunner, of Leoben, has, by means of different alloys and various metals, attempted to determine the temperatures of two furnaces in Carinthia, and this distinguished metallurgical chemist further endeavoured to ascertain, by actual exposure of ore at different depths of the furnace, the exact point at which reduction began, and the various degrees of rapidity with which it was effected. This he accomplished by employing a small iron box, with the top and bottom provided with apertures, so that a portion of the gaseous contents of the furnace, passing through its interior, might heat and then deoxidise any ore placed therein.

This apparatus was introduced into the furnace, and permitted to descend to different depths along with the usual materials, and was then drawn up by means of a windlass. A series of such trials led to the Professor laying down a diagram of the rate of reduction observed, which it would appear barely commenced at a temperature of 680° C. (1265° F.)

The sketch here is copied from Professor Tunner's description of the experiments he conducted. In the figure the line, *a*, *b*, *c*, marks his ascertained zone of reduction, and *d*, *e*, *f*, the region of carburisation. Alongside of it is a diagram compiled from his results, to show the different temperatures at various depths of the furnace, as obtained by means of the alloys and metals, the fusing points of which were previously ascertained.

FIG. 106.

SCHEERER.



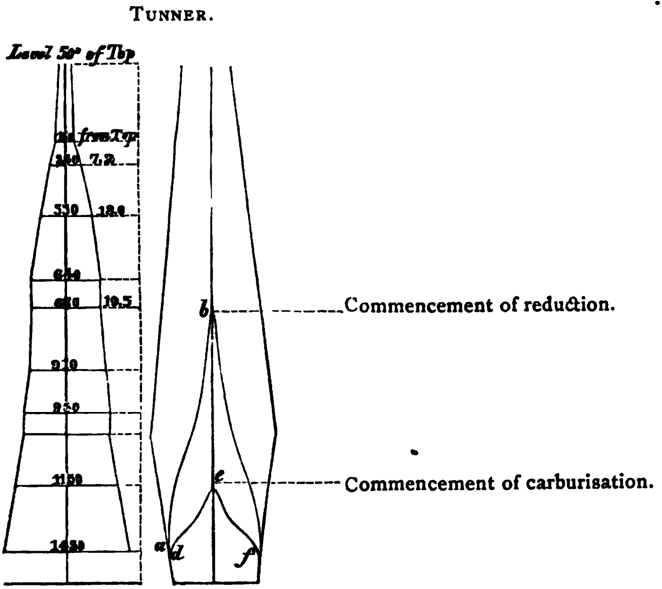
It will be observed that Professor Tunner marks a depth of about 20 feet from the throat as the commencement of the process of reduction, which was reached seventy minutes after the ore was introduced into the furnace, and at which the temperature was as high as 700° C. (1292° F.)

I am not acquainted with the means Scheerer employed to obtain the data upon which he constructed his diagram, but it will be observed there is a marked difference between the views of this chemist and those just described.

Upon Scheerer's figure I have laid down, for the sake of comparison, the curved lines, *a*, *b*, *c*, and *d*, *e*, *f*, to mark the beginning of the reducing and carburising zones, according to the principle adopted by Professor Tunner.

Ebelmen, at Clerval, in France, by means of apparatus similar to that employed by Tunner, ascertained that reduction commenced at a depth of 8·2 feet from the top, after the

FIG. 107.

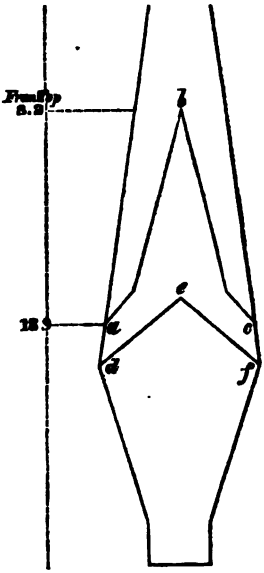


ore had been two hours in the furnace, and that it was completed at a depth of 18·9 feet from the throat after an exposure of 6 hours 25 minutes, by which time incipient fusion had set in. The line, *a*, *b*, *c*, represents in the adjoining sketch the rate of reduction as observed by Ebelmen, and *d*, *e*, *f* will be something like the upper limit of his supposed zone of carburisation.

My own experience leads me to question whether any such lines of demarcation as those described by the authorities just quoted can be laid down in any blast furnace, because to do this within any reasonable limits, would require that each fragment of ironstone is descending with the same speed as all those introduced at the same time, and that every piece is susceptible of being deoxidised as rapidly as the remainder. Now neither of these conditions prevails; on the contrary, the very reverse is known to take place. The friction of the materials against the sides of the furnace, particularly when they reach the slopes immediately above the tuyeres, retards considerably the descent of those portions exposed to its influence. This is a recognised fact within the observation of every furnace manager, who knows that any change in the relative proportions of the minerals does

FIG. 108.

EBELMEN.



not make its presence felt at the lower part of the furnace with all the suddenness with which it was made at the top; but the alteration in the working takes place somewhat gradually, as if the first charges of the change presented the apex of a cone.

The uniform motion of the mass downward is further liable to considerable disturbance by the smaller pieces of ironstone outrunning the larger, by slipping through openings in the contents of the furnace, a mode of progress which cannot happen with those of larger dimensions.

The correctness of this supposed interference of a uniform downward motion of the materials in a blast furnace, was confirmed experimentally by the elder Tunner, who filled one with a given quantity of charcoal before he put in any ore, and also at the same time placed in different positions in a given horizontal section pieces of marked wood. Instead of lighting the furnace when it was thus filled to the top, Tunner drew out its contents by manual labour, by which means he ascertained that portions of the ore arrived at the bottom in little more than one-third of the time occupied by the charcoal introduced at the same period. In like manner the marked pieces of wood placed near the middle of the furnace came down much more rapidly than those which had been retarded by rubbing against the wall of the structure.

Again, the size of the pieces of ironstone exercises a marked influence on the rapidity of the chemical action, which the oxide of iron has to undergo during its passage through the upper portion of the furnace: supposing, therefore, two pieces of ore to be travelling side by side, one containing a cubic inch of matter, and the other a cubic foot, the metal in the former will be nearly perfectly reduced almost before any action has commenced on its neighbour. In like manner the expulsion of the carbonic acid from the limestone will be greatly retarded by the size in which this mineral is employed in the process of smelting.

The same delayed action will happen, if a considerable quantity of small material is permitted to accumulate in a given portion of the interior of the furnace; indeed, there is, perhaps, no circumstance which more frequently deranges the operation than this, unless special precautions are adopted to prevent its occurrence. Tipping the materials into one side of a furnace, by which the greater portion of the fuel, and the larger pieces of ore and limestone, run to that opposite, never fails to act in a most prejudicial manner. I have seen furnaces have their weekly make increased by nearly one-half, and their consumption of fuel economised to an extent of 30 per cent by simply altering the mode of charging. Upon another occasion the throat of the furnace was reduced from a diameter of 4½ feet to one of 3 feet. The effect of this was concentrating, as it were, the smaller pieces into a column; because, as soon as the materials reached the wider part of the furnace, the larger fragments would roll to the outside. This column, more or less unbroken, would descend to the hearth, and from its impervious character, in an imperfectly deoxidised condition. This gives rise to a cooling action in that part of the furnace where the heat is required to be the most intense, and unreduced oxide of iron, acting as a base, enters into the composition of the slag, and thus causes a loss of metal, as well as a deterioration in the quality of the product. It is, perhaps, worthy of remark, that a temperature represented by 2,000 units per minute, according to the French scale, is sufficient to reduce the quality of the iron one number in the scale. When it is remembered that this represents only about 2 lbs. of coke, the assertion that the smelting of iron, in spite of its apparent roughness, is a somewhat delicate operation, will scarcely be considered as an exaggeration.

The information which is sought to be obtained respecting the temperature of the different sections of a furnace is attended necessarily with considerable difficulty. The materials which occupy the interior are difficult of penetration, and the temperature itself is so high as to offer serious obstacles to its estimation; there are, besides, constant changes in the character of the chemical action, which necessarily will cause corresponding changes in the temperature of any particular locality. These variations may be increased from alterations in the direction of the current of heated gases, as they meet with greater or less opposition to their progress, and the nature of the fuel itself may, by the increased power its texture may confer on it of decomposing carbonic acid, all tend to complicate the question.

Tunner and Ebelmen's mode of judging of the rate of the reduction might be accepted as an indication of what it is under the most favourable circumstances as to size, inasmuch as in their apparatus of limited capacity they only introduced pieces of ore having very small dimensions. The very circumstance, however, of the mineral being encased within a box introduces an element of difference between the samples under experiment and those in the furnace. My own observation would indicate that the oxide of iron, when exposed to the unimpeded action of the gases of a blast furnace, is reduced at a temperature considerably below that assigned by any of the authorities already referred to, and further, that the rapidity of the process is materially interfered with by any protection like that involved in the use of such a vessel as that described by Messrs. Tunner and Ebelmen.

I will now, as briefly as possible, give you the reasons, founded on actual experiment, which have led me to adopt opinions in reference to this portion of the action of a blast furnace which are at variance with those of others; whose writings I have consulted, as containing the latest observation on the subject.

It may be remarked, in the first instance, that the material operated upon was the ironstone of Cleveland, but in order to ascertain to what extent previous experimenters had obtained results differing from my own, by the use of other varieties of ores, specimens of red and brown hæmatites and spathose ore were subjected to the same mode of treatment as that pursued with the stone smelted in our own furnaces.

In order to form some judgment of the temperature and rapidity with which the oxide of iron in the calcined oolitic ironstone of Cleveland was reduced by means of carbonic oxide, a glass tube was filled with pieces about the size of hemp-seed, and heated short of redness, probably about 300° C. (600° F.) In this state a stream of carbonic oxide was passed over it, and the resulting gas collected and examined. It contained 96 per cent of carbonic acid, showing that a very small proportion of the original gas had escaped unchanged by the oxide of iron. A portion so treated was then examined, and found to have, in the space of fifteen minutes, lost 39 per cent of its oxygen.

After this a very large number of specimens of calcined ironstone were exposed at various times to the escaping gases of the furnaces at the Clarence Iron Works for periods from one to ninety-six hours. The furnaces vary in height from 48 to 80 feet, with a capacity of about 6,000 to 26,000 cubic feet. As might be expected, the escaping gases differ in temperature according to the dimensions of the furnace—those from the larger being cooler, by their passage through a greater quantity of solid material before they reach the top where the outlet is placed. The ironstone, broken to about the size of hazel-nuts, was placed about 6 or 8 feet from the furnace in the tube for conducting the gas to the boilers and hot-air stoves.

The commencement and termination of the process of reduction, it will be recollected, was given as follows :—

| | Began. | Ended. |
|---|---|---|
| By Scheerer .. | 400° C. (752° F.) | 1000° to 1200° C. (1832° to 2192° F.) |
| „ Tunner .. | 680° C. (1256° F.) | 1400° (2552° F.) |
| „ Ebelmen .. | Below red heat. | Incipient fusion of ore. |

If, then, it can be shown that the temperatures of the escaping gases at the Clarence furnaces rarely exceeded the lowest of these, and frequently were considerably below that, it follows, if these figures are correct, that little, and in most cases, no oxide of iron could have been reduced when exposed to their influence.

The specimens, previously thoroughly dried, were examined for iron before and after exposure, and the difference would enable us to estimate the loss of oxygen, should any take place.

The following table will afford at a glance the results of these trials, among which there occurs only one single instance in which no change in the composition as regards oxygen appears to have been effected :—

| Furnace Number. | Cubic Capacity approximatively. | Hours of Exposure. | Remarks. | Indications of Temp. | | | Loss per cent of original O. |
|---|---|---|---|---|---|---|---|
| | | | | Melted. | Softened. | Not affected. | |
| 2 | 11,600 | 1 | After dinner hour. | Bi | | Pb | 4·20 |
| 6 | 26,500 | 1 | | Bi | Pb | Zn | 5·31 |
| 7 | 15,400 | 1 | | Bi | Pb | Zn | 4·20 |
| 4 | 6,000 | 1 | | Pb | ·Pb | Zn | 5·31 |
| 2 | 11,600 | 2 | Includes dinner hour; no charging. | Bi | Pb | „ | 4·75 |
| 7 | 15,400 | 2 | | Bi | Pb | „ | 4·75 |
| 6 | 26,500 | 2 | | Bi | Pb | „ | 6·10 |
| 4 | 6,000 | 2 | | Pb | | „ | 11·83 |
| 6 | 26,500 | 3 | Furnaces all quite full. | Bi | | Pb | 0·00 |
| 2 | 11,600 | 3 | | Bi | Pb | Zn | 0·97 |
| 7 | 15,400 | 3 | | Bi | Pb | Zn | 4·75 |
| 4 | 6,000 | 3 | | Pb | | „ | 6·10 |

| Furnace Number. | Cubic Capacity approximatively. | Hours of Exposure. | Remarks. | Indications of Temp. Melted. | Indications of Temp. Softened. | Indications of Temp. Not affected. | Loss per cent of original O. |
|---|---|---|---|---|---|---|---|
| 4 | 6,000 | 6 | Trial continuous. Record of temperature means since each preceding observation. | Zn | | Sb | 50·51 |
| ” | ” | 12 | | Sb | | | 52·66 |
| ” | ” | 18 | | Zn | Sb | | 58·19 |
| 6 | 26,500 | 24 | Trial continuous at each furnace; samples exposed in a perforated box. | Pb | | Zn | 3·72 |
| 4 | 6,000 | 24 | | Zn | Sb | | 35·77 |
| 6 | 26,500 | 48 | | Pb | | Zn | 5·71 |
| 4 | 6,000 | 48 | | Zn | | Sb | 48·83 |
| 6 | 26,500 | 72 | | Pb | | Zn | 27·82 |
| 4 | 6,000 | 72 | | Sb | | | 54·02 |
| 6 | 26,500 | 96 | | Bi | | Pb | 27·16 |
| 4 | 6,000 | 96 | | Sb | | | 57·12 |
| 2 | 11,600 | 24 | Sample on tray. | Not recorded; probably melting point of Sb. | | | 53·64 |
| 4 | 26,500 | 24 | | | | | 100·00 |

It is only right to remark that, partly from a little dust being liable to be deposited on the specimens during exposure, and partly from other causes which will be hereafter spoken of as adding to the weight, the result given in the column showing the loss of oxygen is rather under than overstated.

Conceding that the gases from the largest furnace are the coolest, as really happens, and those from the smallest the hottest, the deoxidation, as might be expected, is the most vigorous from the furnace of the least dimensions, and generally speaking, decreases with each addition to the capacity.

It will also be observed that where the fragments of ironstone were placed, not on an open tray but in a perforated box, something after the method pursued by Messrs. Tunner and Ebelmen, the amount of reduction was sensibly interfered with.

In the instance of the last sample mentioned in the list, where all the oxygen was removed, the gas given off by the addition of hydrochloric acid was found to be entirely hydrogen, with the exception of a small quantity of carbonic acid, which existed in the ore previous to exposure.

On examining the composition of the gases taken from that part of the Wrbna furnace where, according to the former gentleman, deoxidation first manifests itself, it was noticed that they contained a very much smaller proportion of the reducing agent, viz., carbonic oxide, than those to which the samples had been exposed at the Clarence works; and as this difference might possibly affect the rate of the action on the ore, 15 litres of a mixture were prepared, resembling, so far as carbonic oxide, carbonic acid, and nitrogen are concerned, the composition of the Wrbna gases, and a similar quantity corresponding, in respect to these substances, with the gases of the Clarence furnaces.[*]

These quantities were separately passed over Cleveland calcined ironstone in 1 hour and 45 minutes in one case, and in 1 hour and 50 minutes in the other. During the progress of the experiments twelve samples of each were collected and tried for carbonic acid. From that resembling the gases in Professor Tunner's investigations, the average volume of carbonic acid was 28·4 per cent of the whole, and in the case of the gases of the Clarence furnaces, 35·7 of the total volume.[†] Both of these results indicate almost complete conversion of carbonic oxide into carbonic acid, but of the two the Wrbna mixture is a trifle more perfect, proving thus that the want of power of deoxidation was not due to its lesser proportion of carbonic oxide.

The next point to be ascertained was whether the Cleveland ironstone was not more susceptible of the deoxidising power of the furnace gases than ores generally are found to be. For this purpose a specimen of red ore of a very close grain was selected from Weilburg, a brown ore from Wetzler, and a spathose one from Herdorf. They were calcined to drive off water and carbonic acid, and then exposed for 7½ hours in the escaping gases of No. 2 furnace at the

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[*] Composition of gases used in experiment by volume:—

| | $COH_1$ | $CO_2$ | N | | |
|---|---|---|---|---|---|
| Wrbna .. .. | 13 | 16 | 71 | = | 100 |
| Clarence .. .. | 32 | 6 | 62 | = | 100 |

[†] Volume per cent of carbonic acid. Particulars of twelve trials:—

| | per cent. | | | per cent. | |
|---|---|---|---|---|---|
| Wrbna .. | 27·4 | 28·4 | Clarence .. | 32·6 | 34·9 |
| ,, .. | 28·4 | 28·1 | ,, .. | 34·9 | 33·9 |
| ,, .. | 27·9 | 27·9 | ,, .. | 36·8 | 36·0 |
| ,, .. | 28·9 | 28·6 | ,, .. | 37·0 | 36·0 |
| ,, .. | 29·0 | 28·8 | ,, .. | 38·0 | 36·0 |
| ,, .. | 29·0 | 28·6 | ,, .. | 37·4 | 36·0 |

Clarence works. This furnace has a cubic capacity of 11,600 feet, and in two hours had, upon a previous occasion, expelled about 5 per cent of the oxygen contained in the calcined Cleveland stone.

In the 7½ hours the Weilburg red ore lost 11·99 per cent of its oxygen, and the Wetzler brown ore 16·88; the spathose ore was also evidently acted upon, but to what extent has not yet been determined.

The larger pieces of ironstone which are here exhibited after an exposure of 24 hours to the gases of blast-furnaces, prove that, although mass may retard the action, and even delay its commencement until sufficient heat has been imparted, a temperature considerably below that stated by the distinguished foreign chemists whose names have been given, is sufficient to completely deoxidise ores of iron. No doubt for this time is required, but partial reduction appears to be effected much more quickly than their observations would lead us to suppose.

Although we have hitherto been considering carbonic oxide as the sole reducing agent in the gases of the blast furnace, there are three other substances often found associated with it, which are also capable of removing oxygen from the compound this element forms with iron. They are hydrogen, cyanogen, and ammonia. In the case of a furnace employing well-burnt coke from which the hydrocarbons are completely volatilised by the coking process, the only source of hydrogen will be the hygrometric moisture driven in with the blast, for all water which may be present in the materials in use will probably be expelled before it arrives at a depth where the temperature is sufficiently elevated to effect its decomposition. In charcoal, circumstances are different, for Bunsen found in it 2 to 3 per cent of hydrogen, which was only completely expelled on the application of a white heat.

I believe the generally received opinion is that, notwithstanding the strong affinity which hydrogen has for oxygen, and the extreme readiness with which it abstracts this latter gas from its combination with iron, it plays no part as a reducing agent in the blast furnace. Although, according to Magnus, its reducing power over oxide of iron commences at

360° (670° F.) it would seem, if the supposition of its inertness in the blast furnace be correct, that the presence of so large a quantity of carbonic oxide found there must interfere with the exercise of its action on the iron ore. Almost all the analyses which I have consulted exhibit a gradual increase in hydrogen towards the mouth of the furnace, as if the gradual rise in heat which the charcoal meets in descending expelled this gas without its being altered by contact with the oxide of iron, heated although the latter was to a point to admit of its reduction by hydrogen.

With regard to cyanogen, this substance is obviously generated by the presence of soda and potash, producing cyanides of the metallic bases of these alkalies, by determining the union of carbon and nitrogen. The formation, however, of cyanogen by no means appears to be an invariable consequence of the existence of these alkalies, for I have before me a sample of a mixture of the two, which was collected near the tuyeres of one of the Clarence furnaces, and in it no cyanogen appears to be present.

Messrs. Bunsen and Playfair, in their celebrated report to the British Association, assigned an important part to the reducing agency of this compound. Dr. Percy mentions that the proportion in which cyanogen occurred in the blast-furnace at Alfreton, the scene of their experiments, was so small that it was only equal to reducing 3·75 per cent of the make. This furnace is only 39·4 feet high, and the only place where cyanogen was detected by these chemists was 34 feet from the top, a point where, judging from that which has preceded, there ought to have been no oxide of iron requiring reduction.

The fact of the disappearance of the cyanogen almost immediately after its production, can be probably accounted for on other grounds than its supposed action on oxide of iron. I found that one volume of it mixed with two volumes of carbonic acid, and passed over quartz pebbles heated to redness in a green glass tube, was decomposed with deposition of carbon.

It is true, nevertheless, that the mixture of these two gases in the proportions given was found capable of removing oxygen from oxide of iron; for in 15 minutes calcined Cleveland stone lost 3·42 per cent of its oxygen at a temperature short of redness, and when the heat was raised until the glass softened, 25·14 per cent of the original oxygen was expelled.

The only instance in which ammonia ever came under my notice in a blast furnace was in the form of chloride, which dropped, associated with other salts and water, from the gas tube, upon the occasion of using raw instead of calcined ironstone, by which the temperature of the escaping gases was reduced to about 40° C. (104 F.)*

At a temperature short of redness, ammoniacal gas was ascertained to deprive Cleveland calcined ironstone of 2·85 per cent of its original oxygen, and at a low red heat 17·71 was expelled. In each case the operation was continued for twelve minutes, free ammonia escaping from the open end of the tube.

Whether this alkali ever exists in a condition to enable it to act as a reducing medium in a blast furnace I am unable to say; one thing, however, may be accepted as certain, viz., that the quantity is never such as to render its action of any importance in the operation of iron smelting, nor shall we be far wrong in assuming that, for all practical purposes, carbonic oxide is the sole reducing agent, to which must be referred the duty of deoxidising the ores of iron in the furnace.

During the passage of the reduced iron through the furnace, and under the influence of the high temperature to which it is exposed on its way to the hearth, the metal is apt to carry down some of those substances with which it was originally associated in its ore, or which it meets with in the flux or fuel employed. To such an extent may this occur that Fresenius quotes a case in which he detected and estimated the quantity of not less than twenty substances other than iron in a specimen he analysed. In some cases as much as 22 per cent of manganese has been found in pig-iron, and above 5 per cent of silicon, the presence of the former due to the ore employed being rich in that metal, and the latter

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* Composition of the substance was as follows :—

| Insoluble. | Chloride Ammonium. | Chloride Iron. | Chloride Zinc. | Water. | | |
|---|---|---|---|---|---|---|
| 1·0 | 52·9 | 14·7 | 6·6 | 24·8 | = | 100 |

derived probably from the temperature of the furnace being high enough to decompose the silica invariably present in the materials under treatment in a blast furnace. That neither of these elements, nor all the others mentioned by Fresenius, with one exception, are essential constituents of pig-iron, is proved by the circumstance that although no cases, perhaps, are known where none occur, every one or other is occasionally absent. The one exception is carbon, which may, therefore, be looked upon as a necessary ingredient of all pig-iron.

The circumstances which determine the union of this indispensable element with the metal, are of high interest to the smelter, because upon the condition in which the carbon is associated with the iron depends, it is considered, the different qualities of the article he is manufacturing.

The portion of the furnace in which the combination takes place,the temperature necessary for effecting it, and the exact source of immediate supply, have engaged the attention of all chemists who have studied the subject.

Scheerer assigns to it something like the position described by the line *d*, *e*, *f*, in his section, where the operation, he states, is effected after all traces of unreduced oxide have disappeared, and where the temperature ranges from 1000° to 1600° C. (1832° to 2912° F.)

Tunner, by means of his perforated box, containing fragments of calcined ore, determined that carburisation did not take place until a depth of 29·8 ft. from the top of the furnace was reached, where the temperature ranged about 1500°C. (2102° F). This patient investigator, indeed, deduces from the known heat at which carbon unites with iron, in the process of cementation, the temperature of this portion of the furnace, which, he states, accords with what it ought to be, from a direct observation made 4·33 feet higher up. He further lays down the limits of the zone, marked *d*, *e*, *f*, on his section, in which the union of the carbon with iron is accomplished.

Upon the sketch intended to show Ebelmen's idea of the zones of reduction and carburisation, the latter is somewhat higher up, but, according to his views, no signs of it were apparent until the wrought-iron apparatus was softened by the heat, and the ore itself manifested symptoms of incipient fusion.

The conditions then deemed essential by these three gentlemen were reduction, almost, if not perfectly complete, and a temperature of something like 1000° to 1200° C. (1832° to 2190° F.) Let us now enquire whether it is not highly probable that the exclusion of the full force of the chemical energy, which the gases of the furnace were capable of exercising, by confining the ore in a box, has not interfered with the action of carburising in the same way as happened, in all probability, with that of deoxidising.

In order to ascertain the extent of the change in content of iron, the samples were, after exposure, dissolved in hydrochloric acid, a mode of procedure which afforded, of course, an insoluble residuum.

When a sample of calcined ironstone was exposed for the space of two hours in the waste gases of any of the furnaces, large or small, this residuum was of a colour inclining to grey—not calling for any special notice. The same may be said when the exposure was carried on for three hours in all the furnaces, except those of the least dimensions, from which, as we have already seen, the gases issue the hottest—zinc in them frequently melting, and occasionally antimony. In a furnace of this type, such as No. 4 at the Clarence works, the insoluble residuum under consideration, from a specimen after three hours' contact with the hot gases, was blackish, and this colour went on increasing in intensity as the exposure was prolonged, until it became perfectly black. On the other hand, No. 6 furnace, having above four and a half times the capacity of No. 4, or 26,500 cubic feet instead of 6000, never gave off its gases, during a period of observation extending over 96 hours, hot enough to melt zinc; for during 72 hours of this time lead melted, and for the last 24 hours bismuth only was fused. Ironstone, exposed during these 96 hours, only afforded a greyish insoluble residuum on being treated with hydrochloric acid.

These observations have led me to conclude that an exposure of three hours to a temperature a little above the melting point of lead, and below that of zinc, sufficed to give the black colour, whereas at about the temperature at which lead fuses no period up to 96 hours sufficed to produce it. Probably, if we give 337° C. (630° F.), as being below the heat necessary to give the blackness, and 361° C. (700° F.) equal to afford it, we shall not be wide of the truth.

On examining into the cause of this blackening, it was found to consist of carbon, inasmuch as it totally disappeared on the residuum being heated in contact with air, and on passing a current of pure oxygen over it, vivid combustion was produced and carbonic acid generated, which was recognised in the usual way. This carbon, moreover, exists in such a minute state of division as to induce me to believe that it is really combined with the iron, or is deposited by chemical action in such a form as to present great facilities for subsequent combination. It therefore seems probable that, instead of the lowest and hottest portion of the furnace being the zone of carburisation, this change occurs high up, where the temperature is comparatively low. Neither does it appear that anything approaching to complete deoxidation is required; for in one case where only 6·10 per cent of the oxygen of the ore was driven off, the residuum was blackish, and with anything like 50 per cent of loss of oxygen the colour is intensely black. On the other hand, oxygen may be removed to the extent, at all events, of 28 per cent, and no strongly marked signs of carbon appear in the residuum, if the heat during exposure has not reached the necessary point of elevation.

The amount of carbon associated with the iron was determined in those cases where the exposure of the ore had been effected in a box with perforated sides and open at the top. The residuum from ore, after

48 hours' exposure, lost 48·83 per cent of its oxygen, and contained of the weight of iron . . . . . . 2·42 C. per cent.
72 hours' exposure, lost 54·02 per cent of its oxygen, and contained of the weight of iron . . . . . . 3·09 C. ,,

while, in another instance, where the ore was placed on an open tray, all the oxygen was gone, and carbon, to the extent of 3·26 per cent of the weight of iron, was found in the residuum.*

It may be observed that the residuum from all the samples of foreign ores, exposed for seven and a half hours in the gases from a furnace of medium size, showed unmistakeable signs of carbon having been deposited.

Admitting the correctness of the opinion just laid down, the following formula would account for the action, when the deoxidation and carburisation is complete:—

$$8CO + 2Fe_2O_3 = 7CO_2 + 4FeC.$$

I am, however, by no means satisfied that this equation conveys a true explanation of the action, for within the last few days I was desirous of ascertaining how far the introduction of the Cleveland ironstone in its raw state, *i.e.*, as carbonate of iron, would retard the deoxidation. The extent of this is immaterial, but what is of importance is that a very considerable increase in the quantity of this deposited carbon took place in each sample exposed.

Here are five specimens of each, viz., the insoluble, from the ironstone, raw and calcined, before they were placed in the escaping gases of No. 4 furnace, the others being the insoluble and blackened residuum after the two varieties, exposed at the same time, had been in for 6, 12, 18, and 24 hours.

In the case of the raw ironstone, the colour was so much blacker than when the calcined ore was used that the quantity of carbon in each was carefully determined. With the calcined ore it amounts to 1·68 per cent of the iron, while in the raw stone it is 4·63 per cent of the iron, after each had been exposed twenty-four hours in the escaping gases.†

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* Time did not permit the necessary analyses being made, so as to obtain with exactness the whole of the carbon. To estimate the iron, a solution in hydrochloric acid was made, during which probably a portion of the carbon was lost, and I was obliged to content myself with examining the insoluble left after treating the samples with this acid.

† *a*. Insoluble from 100 grains of calcined ironstone, in which organic matter must have been destroyed, was dried at 193° C. (380° F.):—

Heated to redness in contact with air, lost .. .. .. .. .. 0·15 gr.

*b*. Insoluble from 100 grains of calcined ironstone, same as above, It was then deemed desirable to ascertain to what extent carbon might be caused by any organic matter existing naturally in the ore and retained in the ironstone, while the latter was imperfectly calcined, and, consequently, before the carbon so formed was entirely burnt off.

When the insoluble residuum from this source was thrown into melted nitrate of potash, the faintest trace of carbon made itself apparent, whereas with that obtained in either of the two instances previously quoted, deflagration of some violence was produced.

In the minds of all practical smelters, there is no doubt entertained, that the hotter a furnace is working, the richer is the iron in graphitic carbon, or "kish," as they term it. This, together with the circumstance, that when the temperature is very high, flakes of this substance escape in considerable quantities when an opening is made above the dam of the furnace, probably has favoured the belief, that the region of fusion was the chief seat in which the union of carbon with the iron was accomplished.

It is, perhaps, a little premature to speculate upon the nature of the origin of carbon in pig-iron by aid of facts, many of which have only been ascertained since this paper was begun, and some investigated so lately as yesterday. It may, however, be observed, that although this substance exists in pig-iron in two distinct forms, viz., as combined,

previously exposed in waste gases of No. 4 Clarence furnace for twenty-four hours:—

Dried at 193° C. (380° F.), and then heated to redness, lost.. 0·88 gr.
Deduct for loss assumed as independent of carbon.. .. .. 0·15 ,,

Leaving for carbon .. .. .. .. .. .. .. .. .. .. 0·73 ,,

Specimens contained 43·5 per cent of iron. Carbon, therefore, is equal to 1·68 per cent.

*c.* Insoluble from raw ironstone, exposed as such, in gases from No. 4 Clarence furnace, for twenty-four hours. Insoluble from 100 grains of the ironstone weighed after exposure:—

Dried at 193° C. (380° F.) and then heated to redness, lost .. 1·90 gr.
Deduct for loss assumed as independent of carbon.. .. .. 0·15 ,,

Leaving for carbon .. .. .. .. .. .. .. .. .. .. 1·75 ,,

Sample contained 37·8 per cent of iron, hence iron is associated with 4·63 per cent.

and as uncombined or graphitic, there is nothing antagonistic in the idea of carbon uniting with iron in that portion of a furnace, where no such difference of temperature is ever found likely to produce at one time white iron, in which the iron is chiefly in the combined form, and at other times grey iron rich in uncombined carbon. It is, I imagine, quite consistent with all observation to suppose that the ore during or after the process of reduction may absorb all the carbon it requires, but the form this element may assume in the pig-iron produced will depend on the temperature when fusion takes place. This explanation is corroborated by the well-known fact, that white iron may be run from the blast furnace, and be changed to grey by slow cooling, and the richest No. 1 iron may be reduced to No. 3, or even rendered white by chilling it suddenly against a surface of cold metal, proving thus, that it is the latest condition of things previous to solidification which determines the character of the carbon, rather than the mode in which it has found its way into the metal.

As to the flakes of "kish" flying about a furnace making rich iron, it is possible they may be produced by the decomposition of the oxides of carbon under the influence of the high temperature and chemical action, or even by the decomposition of cyanogen, for I ascertained that this compound not only deposited carbon when heated along with carbonic acid, but that it also, at a temperature of redness, conferred carbon upon iron, of which it had effected the reduction.

A consideration of the other occasional constituents of pig-iron would carry us far beyond the limits of such a discourse as the present; we will, therefore, pass on to review, in as condensed a manner as possible, the behaviour of lime in the blast furnace.

One duty, but not the only one, performed by this earth, generally added in the form of its carbonate, is to act as a flux, by melting and separating the solid impurities of the ore under treatment. The labours of Berthier informed us how the fusibility of any two earthy substances was promoted by the addition of a third, and what an extended range of proportions could then be used without seriously interfering with readiness of fusion. This chemist further showed how the presence of a fourth or more substances, even in very small quantities, augmented fusibility. Were it not for these laws, the smelting of many of our ores would be a matter of great difficulty, if not of impossibility, owing to the endless variety of the proportions in which silica, alumina, lime, and magnesia are found associated with the metal.

Dealing with these earths alone, silica occurs in every proportion from 30 to 70 per cent of the whole, alumina from 20 to 30 per cent, lime from 4 to 27 per cent, and magnesia from 3 to 19 per cent, and this list merely comprehends some of the ordinary ironstones of this country.[*]

It is usually considered that the use of an excess of lime promotes the separation of sulphur, and, it may be, of phosphorus, from the iron produced, for it is frequently added when the earths naturally existing in the ironstone are in such proportions as to constitute a perfectly fusible slag. This is the case with the ore of Cleveland, as was proved by actual experiment in the laboratory, after which, one of the Clarence furnaces had lime gradually removed from the charges until it was entirely withdrawn. So far as the mere office of smelting was concerned, the operation was perfect, *i.e.*, all the iron existing in the ironstone was obtained, and a perfect slag was produced. There was some little practical

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[*] Proportions in which silica, alumina, lime, and magnesia exist in certain ironstones, calculated from analyses contained in geological survey of Great Britain.

| 100 parts consist of | Silica. | Alumina. | Lime. | Magnesia. |
|---|---|---|---|---|
| Darlaston .. | 69 | 24 | 4 | 3 |
| Dudley .. .. | 61 | 29 | 5 | 5 |
| Low Moor .. | 60 | 24 | 9 | 7 |
| Corngreaves .. | 59 | 28 | 8 | 5 |
| Rough Hay .. | 58 | 20 | 11 | 11 |
| Butterley .. .. | 55 | 24 | 10 | 11 |
| Dudley .. .. | 53 | 28 | 13 | 6 |
| Dowlais .. .. | 52 | 23 | 12 | 13 |
| Blaenavon .. | 50 | 21 | 12 | 17 |
| Stanton .. .. | 50 | 20 | 12 | 18 |
| Blaenavon .. | 49 | 25 | 8 | 18 |
| Staveley .. .. | 49 | 25 | 7 | 19 |
| Parkgate .. .. | 44 | 24 | 13 | 19 |
| Dowlais .. .. | 39 | 27 | 15 | 19 |
| Cleveland .. .. | 31 | 29 | 27 | 13 |

difficulty connected with working the furnace, but the inconvenience which was anticipated occurred,—the iron, No. 3, contained much more sulphur than when using lime, viz., 0·33 per cent, and its quality, in point of strength, suffered considerable deterioration.*

It will be impossible for us, upon the present occasion, to dwell, at any length, upon the distinctive characters which mark blast furnace slags, which have compositions embracing so extensive a range of variations in their constituent parts. This interesting series of compounds, occasionally, when silica is in sufficient quantity, possesses the properties of true glass, gradually changing into substances of a perfectly stony nature, in which no trace of vitrification is usually perceptible. This is particularly the case when alumina is in such quantity as probably to divide with silica the functions of an acid.

Mention has already been made of the difficulty which accompanies drawing any general conclusions respecting the progress of the operation of smelting from an examination and analysis of the solid contents of a blast furnace.

Probably the most elaborate investigations into the nature of the gases taken from various depths of a blast furnace are contained in the communication by Messrs. Bunsen and Playfair to the British Association in 1845. Judging from the drawing which accompanies the paper, the furnace at Alfreton was charged in the defective way already spoken of, viz., at one side only of the throat. It may, therefore, be questioned whether the current of gaseous matter would have anything like a uniform composition over any horizontal section corresponding with the point where the samples were taken.

Imagine a furnace in which pure oxide of iron is being smelted by pure carbon; now, so long as the oxide was reduced in the upper and cooler portions, the extent of carbonic

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* Sulphur in Clarence iron:—

| | | | |
|---|---|---|---|
| No. 1 iron | .. 0·04 per cent. | No. 3 | .. 0·10 per cent. |
| ,, | .. 0·25 ,, | ,, | .. 0·17 ,, |
| ,, | .. trace | ,, | .. 0·04 ,, |

Vide Paper by I. L. Bell, on Cleveland Iron Manufacture, read before British Association at Newcastle, 1863.

acid would be a correct indication of the nature of the process carried on; but wherever deoxidation is delayed, as no doubt may happen, until that depth is reached, when the high temperature would decompose this acid, then the gases afford no indication of the change effected on the solid contents of the furnace.

When we come to consider the properties of carbonate of lime when exposed to heat in an atmosphere of carbonic acid, the problem of drawing from the presence of this gas any general inference of the chemical alteration going on in a furnace becomes very intricate, if, indeed, not impossible.

This salt of lime, as is well known, parts with half its carbonic acid at a moderate red heat, a much higher temperature being required before the whole is expelled. In the solution of the question just mentioned, we have to determine not only whether all the iron is deoxidised, but also whether the temperature is such as will drive off carbonic acid from the limestone, and then whether the heat is sufficiently high to decompose the carbonic acid from either source. In the case of the ore, it is quite possible that all the carbonic acid resulting from its decomposition may be formed when this change would be impossible; but in that of the limestone it is pretty clear the last half, more or less, will not be set free until, meeting with hot carbon, it is instantly resolved into carbonic oxide.

It is by no means an uncommon thing for iron smelters to use caustic lime in their operations; this, however, does not simplify the inquiry, but rather the reverse. Up to a temperature of redness such as to soften green glass, I ascertained that lime absorbed carbonic acid in proportion to the temperature to which it was exposed, *i.e.*, the higher the heat, the more rapid was the union—this absorption went on until 19 per cent of the weight of the lime was taken up, after which a stream of the gas, continued for nine hours, produced no further change. On the other hand, carbonate of lime and caustic lime were subjected to a current of carbonic acid in a porcelain tube, and heated until the latter began to soften. In this case there was no absorption of carbonic acid, on the contrary, all the acid was driven off from the carbonate.

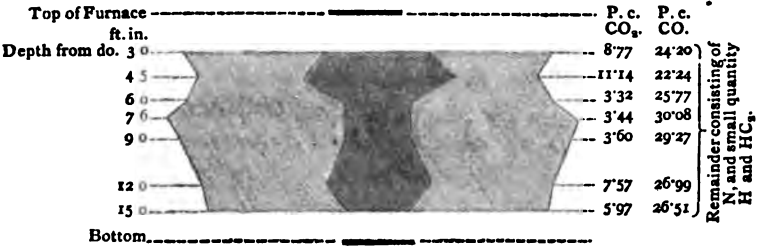
So far as moderate temperatures are concerned, it was ascertained that caustic lime rapidly absorbs carbonic acid from the escaping gases,* so that, in addition to not knowing the rate at which this gas was at any particular point generated by the whole mass of ore, it would be impossible to discover how much of it, so formed, was taken up by the lime, only to be again expelled in the lower and hotter portions of the furnace.

It is almost needless to say that when lime or its carbonate exists in the ores naturally, the same consequences will happen more or less as those described in the case of the earth used separately and constituting the flux.

To afford a clearer idea than figures can do of the want of uniformity in composition of the gases from different depths of furnaces, as determined by analysis, I have constructed a few diagrams, drawn to a scale, in which carbonic acid is shown by the darker shaded part, and carbonic oxide by the lighter. In the four diagrams the scale is according to volumetric analysis, and the authorities quoted.

Locality, Veckerhagen. Authority, Bunsen. Temperature blast, 278° C. (532 F.) Fuel, charcoal.

FIG. 109.



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* Caustic lime exposed for one hour in escaping gases from No. 4 Clarence furnace :—

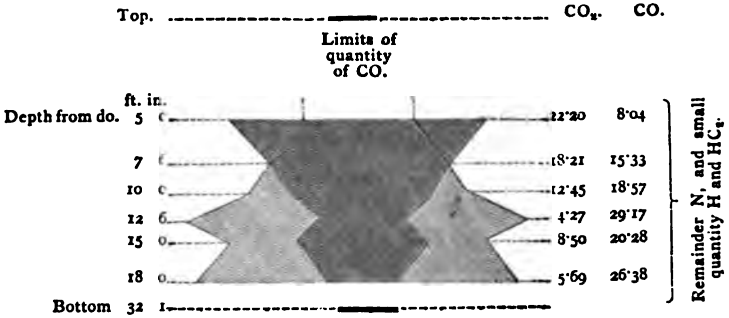
| | |
|---|---|
| Lead melted, zinc not changed, absorbed of its weight of $CO_2$ | 1·28 per cent. |
| No. 7 furnace Bismuth melted, lead not changed | 1·00 „ |
| „ 2 furnace „ „ | 0·96 „ |
| „ 6 furnace „ „ | 0·92 „ |

After two hours' exposure, temperatures as above :—

| | |
|---|---|
| Lime absorbed of its weight in gases of No. 4 furnace | 1·72 per cent, $CO_2$. |
| „ „ „ 2 „ | 0·72 „ |
| „ „ 7 „ | 0·62 „ |
| „ „ 6 „ | 0·52 „ |

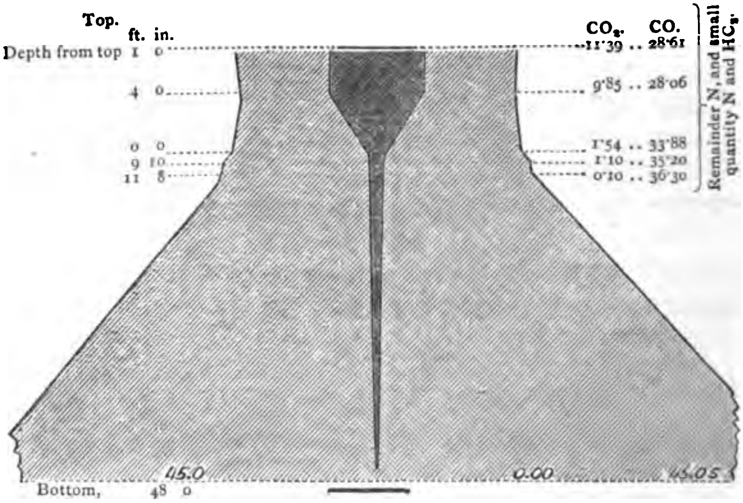
Locality, Baerum. Authority, Scheerer and Langberg. Temperature blast, 200° C. (392 F.) Fuel, charcoal.

FIG. 110.



Locality, Séraing. Authority, Ebelmen. Temperature blast, 100° C. (212° F.) Fuel, coke.

FIG. 111.



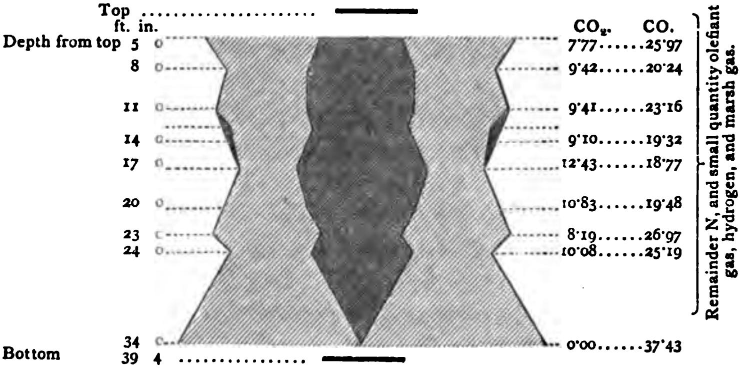
The difficulty which attends obtaining an average sample of the gases below the level of the top of the furnace does not present itself when the object is to procure specimens of the gases after they have left the furnace.

The following portions of gas from No. 4 Clarence furnace, 48 feet high, were carefully taken and analysed, many in my presence, by Mr. W. Moody, the chief assistant in the Washington laboratory. The results, when the trials were repeated, are given, so that some opinion may be formed of the attention bestowed on the experiments.

| Volumes of in 100 Volumes.* | $CO_2$. | | CO. | | N by difference. | |
|---|---|---|---|---|---|---|
| Hour sample taken. | 1st Trial. | 2nd Trial. | 1st Trial. | 2nd Trial. | 1st Trial. | 2nd Trial. |
| 1 p.m | 6·25 | — | 26·30 | — | 67·45 | — |
| 1.55 | 6·24 | 6·70 | 34·70 | — | 59·06 | — |
| 2.15 | 6·94 | 6·73 | 34·40 | 35·40 | 58·66 | 57·87 |
| 3 0 | 5·30 | 5·75 | 35·80 | 35·64 | 58·90 | 58·61 |
| 3.15 | 4·75 | 5·12 | 31·00 | 30·25 | 64·25 | 64·63 |
| 3.55 | 5·91 | — | 31·12 | — | 62·97 | — |
| 4.20 | 5·82 | 6·00 | 29·72 | 28·90 | 64·46 | 65·10 |

Locality, Alfreton. Authority, Bunsen and Playfair. Temperature blast, 330° C. (625° F.) Fuel, raw coal.

FIG. 112.



A very brief examination of the figures contained in the above table proves how liable to variation is the nature of the

---

* The following figures show the above volumetric constituents converted into weights:—

| | $CO_2$. | | CO. | | N by Difference. | |
|---|---|---|---|---|---|---|
| Hour. | 1st Trial. | 2nd Trial. | 1st Trial. | 2nd Trial. | 1st Trial. | 2nd Trial. |
| 1 p.m. | 9·60 | Nil | 25·86 | Nil | 64·54 | Nil |
| 1.55 | 9·55 | Lost | 33·90 | Lost | 56·55 | Lost |
| 2.15 | 10·78 | 10·26 | 34·10 | 34·51 | 55·12 | 55·23 |
| 3.0 | 8·13 | 8·83 | 35·10 | 34·93 | 56·77 | 56·24 |
| 3.15 | 7·86 | 7·33 | 29·78 | 30·59 | 62·36 | 62·08 |
| 3.55 | 9·06 | Lost | 30·50 | Lost | 60·44 | Lost |
| 4.20 | 8·98 | 9·22 | 28·68 | 28·30 | 62·34 | 62·48 |

changes going on in a blast furnace, even when, to all appearance, the materials employed are precisely the same.

If the gases of a blast furnace have to furnish us with any data from which we may endeavour to draw just conclusions of the nature of the chemical action going on in its interior, it appears to me that little reliance can be placed on any analyses, excepting of those of the gases as they escape.

If, as I think most probable, little, if indeed any, carbonic acid leaves the lime until it reaches a portion of the furnace when the heat is such as to resolve the liberated acid into carbonic oxide, it is clear that all the carbonic acid found in the gases must be due to the deoxidation of the ore, which, according to the views laid down in this paper, is effected at a lower temperature than was supposed by Tunner, and at one where carbonic acid is not decomposed by incandescent carbon. The ironstone may be in such large masses, like those on the table, that the whole of the oxygen may not be expelled until a considerable depth in the furnace is reached, and then, of course, the carbonic acid generated by the process of reduction may experience the same fate as that liberated from the carbonate of lime.

It is not a difficult matter to calculate what the composition of furnace gases ought to be, supposing a certain quantity of coke and limestone to be consumed to the ton of iron, and the sole source of carbonic acid to be the ore by its deoxidation.

Assume the coke used to be 23·20 cwts., and the limestone 11·60 cwts. per ton of pig-iron, containing 19 cwts. of pure iron,

The coke may be taken as consisting of—

| | |
|---|---|
| Pure carbon | 21·80 |
| Ash | 1·40 |
| | 23·20 |

And the limestone will consist of—

| | | | |
|---|---|---|---|
| Lime | | | 6·50 |
| Carbon | 1·39 | to form carbonic acid | 5·10 |
| Oxygen | 3·71 | | |
| | | | 11·60 |

The ironstone will consist of—

| | | |
|---|---|---|
| Iron | 19·00 cwts. | |
| Oxygen | 8·14 ,, | |
| Earths | 22·86 ,, | |
| | | 50·00 |

The total carbon then to be dealt with is—

| | | |
|---|---|---|
| In the coke | 21·80 | |
| In the limestone | 1·39 | |
| | | 23·19 cwts. |
| From which must be deducted the carbon to combine with the iron | | 0·74 ,, |
| Leaving to go off as carbonic acid and as carbonic oxide | | 22·45 ,, |

The total quantity of oxygen we have in the minerals applicable to oxidising carbon is in the—

| | | |
|---|---|---|
| Ore | 8·14 | |
| Limestone | 3·71 | |
| | | 11·85 |
| To which may be added from the decomposition of water contained in the blast | | 0·85 |
| Cwts. | | 12·70 |

| | Cwts. |
|---|---|
| To convert 22·45 cwts. carbon to the state of carbonic oxide will require of oxygen | 29·93 |
| But as applicable to this we have in the limestone 3·71, and in the blast 0·85 | 4·56 |
| Leaving to be derived from the atmosphere | 25·37 |
| 25·37 atmospheric oxygen is equal to nitrogen | 84·93 |
| 8·14 oxygen in the ore will give of carbonic acid generated by its action on carbonic oxide | 22·38 |
| 22·38 carbonic acid contains 6·10 of carbon, leaving 16·35 (22·45 — 6·10) carbon to give of carbonic oxide | 38·15 |
| Total weight of gases per ton of iron | 145·46 |

Supposing, then, the carbonic acid from the limestone to be decomposed, and that generated by the reduction of the ore to escape as such, the proportions in which nitrogen, carbonic acid, and carbonic oxide should be found in the escaping gases, would be—

| | |
|---|---|
| Nitrogen | 58·38 |
| Carbonic acid | 15·39 |
| Carbonic oxide | 26·23 |
| | 100·00 |

The analyses of the gases from a blast furnace, making forge iron with precisely the quantity of materials named in the above calculation, gave the following results by weight:—

| Taken at Hour. | $CO_2$. | | CO. | | N by difference. | |
|---|---|---|---|---|---|---|
| | 1st Trial. | 2nd Trial. | 1st Trial. | 2nd Trial. | 1st Trial. | 2nd Trial. |
| 1 p.m. | 18·28 | 18·20 | 27·19 | 27·19 | 54·53 | 54·61 |
| 2.10 | 14·60 | 15·10 | 30·09 | 28·60 | 55·31 | 56 30 |
| 2.40 | 15·05 | 15·58 | 18·61 | 19·50 | 66·34 | 64·92 |
| 3.30 | 18·50 | Lost | 25·80 | Lost | 55·70 | Lost |
| 3.45 | 15·85 | " | 25·50 | " | 58·65 | " |
| 4.0 | 16·12 | 16·41 | 23·00 | 24·88 | 60·88 | 58·71 |
| 4.10 | 19·71 | 19·71 | 23 60 | 23·60 | 56·69 | 56 69 |
| 4.50 | 19·25 | 19·14 | 27·08 | 27·10 | 53·67 | 53·76 |
| Average .. | 17·17 | — | 25·11 | — | 57·72 | — |

These figures show a close approximation to the theoretical calculation, there being rather more carbonic acid, as shown by the analyses, than the previous estimate would indicate, from which it may be inferred that not only the whole of the ironstone was reduced in the upper and cooler part of the furnace, but also that a portion of the carbonic acid which was contained in the limestone was also expelled before the flux reached a part of the furnace where the heat was intense enough to decompose it.*

On watching the slag from a furnace in the Cleveland district as it falls from a spout into the vessel for receiving it, a white fume is perceived. A portion of this may be sulphurous acid combining with hygrometric water, but by far the greater quantity consists of the earths themselves, in the state of vapour, at least such I conceive to be the case. This vapourised lime, alumina, magnesia, and silica, ascend through the contents of the furnace, and are, no doubt, to a considerable extent, condensed as a sublimate on the way, but eventually a certain quantity escapes from the top, constituting the mass of fume visible in most smelting districts, but particularly conspicuous on the banks of the Tees. At one time I supposed this volatilising sufficient to account for a difficulty in reconciling the composition of our slags with the earthy materials which really entered the furnace. This discrepancy I have since ascertained is due to the great variations in the composition of our ironstone itself. As might be expected, the higher the furnace in which the smelting is being carried on the greater is the interception of these vapourised hearths and the other substances associated with them, but the actual quantity varies in the same furnace at different times.

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* This is consistent with observation, for in an experiment mentioned in a discussion before the Institution of Mechanical Engineers, 28th January last, I showed that coke was incapable of decomposing carbonic acid at a temperature which completely melted German green glass. Upon the same occasion I gave it as my impression, that one of the advantages in using high furnaces was that they did not permit the gases to escape at a temperature at which they were still capable of deoxidising the ores. This latter circumstance was also alluded to by the President, Dr. Williamson, in the discussion which followed the reading of this paper. The analyses just quoted were of gases taken from a furnace 80 feet high, and containing about 11,500 cubic feet, so that, as far as chemical action is concerned, its dimensions appear to be sufficient.

From a furnace 48 feet high, the quantity amounted, upon one occasion, to 59·09 lbs. per ton of iron made, and at another to 77·31 lbs., while in an 80 feet furnace the weight for the same quantity of metal was 27·24 and 19·54 lbs. respectively upon the two days when the experiment was made.[*]

---

[*] The estimated weight of slag per ton of iron is about 30 cwts.

The following shows the composition of this condensed fume, taken out of the gas pipes:—

| | | |
|---|---|---|
| Silica and sand | 44·82 | |
| Alumina | 16·00 | |
| Lime | 12·15 | |
| Magnesia | 0·57 | |
| Peroxide of iron | 8·20 | |
| Oxide of zinc | 4·60 | |
| Sulphuric acid | 8·80 | |
| Potash | 0·40 | |
| Soda | 6·85 | |
| Chlorine | 1·56 | |
| Water | 5·60 | |
| | | 99·55 |

Report, I. L. Bell to British Association, 1863.

A second sample was collected by drawing through water for some hours the gases from one of our furnaces, so as to secure the presence of the whole of the solid constituents before analysing. It contained—

To this short account of the gases I would only add that, instead of escaping into the atmosphere and burning at the tops of the furnaces, as formerly happened, and still happens generally in Staffordshire, and uniformly so in Scotland, the carbonic oxide they contain is burnt for raising steam for the blast engines, and for heating the air, by which something like a saving of 600,000 tons of coal per annum is effected in those works smelting the ironstone of North Yorkshire.

Having now traced the progress of the solid materials down through the furnace, and considered the action of the gaseous current flowing upwards among them, let us devote a few minutes to an examination of the blast by means of which we obtain heat from the fuel to fuse the iron and slag, and generate carbonic oxide to effect the reduction and carburisation of the metal, which is the object of the process.

The effect of cold on our atmosphere being to deprive it of a considerable portion of its moisture, and to contract its bulk, a cubic foot of air in winter contains of course less watery vapour and more oxygen than is embraced within the same space in summer.

It is obvious that there is no necessary connection between a rise in temperature and the presence of aqueous vapour and a diminution of the supply of oxygen, but in the absence

| | | |
|---|---|---|
| Soluble in water— | | |
| Loss in heating | 10·46 | |
| Silica | 1·37 | |
| Alumina | 12·20 | |
| Lime | trace | |
| Magnesia | trace | |
| Chlorine | 0·57 | |
| Sulphuric acid | 0·59 | |
| Oxide of zinc | 4·58 | |
| Carbonates of soda and potash | 22·90 | |
| | | 52·67 |
| Insoluble in water— | | |
| Silica | 11·00 | |
| Alumina and oxide of iron | 10·76 | |
| Lime | 2·06 | |
| Magnesia | trace | |
| Oxide of zinc | 13·28 | |
| Carbonic acid | 7·00 | |
| Alkaline salts | 3·07 | |
| | | 47·17 |
| | | 99·84 |

of correct and sufficient information on the subject forty years ago, iron-smelters ascribed some virtue to a blast as cold as circumstances permitted, because in the winter season, as a rule, they made more iron with less fuel than in summer, simply because each stroke of their blast engine supplied them with more oxygen, and less carbon was absorbed in the decomposition of watery vapour than in summer.

Under these circumstances, it is not surprising that Neilson's proposition to heat the blast before it entered the furnace was not favourably received, or that a considerable time elapsed before the value of his invention was recognised by practical men.

It is not my intention to detain you with any comparison between the nature of hot and cold blast iron; indeed, this would be a task beyond my power for want of the necessary data. There is no doubt that some of the best, if not the best, makes of iron in this country are produced by means of cold blast; but whether this excellence of quality is due to the temperature of the air or to the materials employed is a point upon which no opinion of any value can be formed until the same materials have been treated by both systems, and the results experimentally and practically examined.

The fact, however, that out of the four or five millions of tons of pig-iron annually produced in this empire, all but one or two hundred thousand tons are smelted by means of heated air, will be accepted as a proof of the soundness of Neilson's discovery.

The chief recommendation of the hot blast is the economy of fuel obtained by means of its use, and it is this attribute which possesses interest to ourselves as chemists, furnishing, as it does, a field of inquiry into the nature of the combustion and the appropriation of the heat in the blast furnace.

In entering upon an explanation of the action of the hot blast, we must consent to lay aside those accounts which inform us that, immediately after its introduction, the mere heating of the air up to 320° F. (161° C.), enabled a smelter to reduce the consumption of coal for 1 ton of iron from 7½ tons to 2¼ tons.

If it can be shown that the progress of smelting science has been such as to reduce the consumption of coke in a furnace blown with cold air until it is within 10 or 11 cwts. per ton of iron of that used in a furnace supplied with air heated, not to 320° F. (160° C.) but to 650° F. (339° C.), this is the saving we are called upon to explain, and not 5 or 6 tons of coal, however instrumental the employment of hot blast may have been in leading up to those general improvements which have benefitted both modes of operating.

With the view of satisfying myself by personal enquiry what the consumption of fuel in furnaces fed with cold blast actually is, and for obtaining information on the process generally, I have recently visited the establishments of the Lilleshall Iron Company, in Shropshire, of the Blaenavon Iron Company, and that of my friend, Mr. Crawshay, in South Wales, and I cannot deny myself the pleasure of recording in this paper my grateful thanks for the unreserved access which was granted for the purpose of making the necessary experiments and observations.

Granting, then, for the present moment, that a furnace having its blast heated to 650° F. (339° C.), can make a ton of iron for 10 or 11 cwts. less coke than one driven with cold air, this extent of saving, moderate as it is when compared to the 5 tons of former days, requires some explanation, when it is remembered that the blast has the 650° F. (339° C.) of heat communicated to it by means of 5 cwts. of coal, of which I have ascertained that more than one-half is wasted in the hot-air apparatus,* so that practically you have the heat of about 2 cwts. of fuel burnt outside the blast furnace, effecting a saving of that burnt in its interior of 10 cwts. to 11 cwts.

The generally received opinion respecting the mode in which hot air effects the reduction in the consumption of coke is that a higher temperature is commanded in the furnace by its use than when cold air is employed, and, as Dr. Percy truly says in his recent work on "Metallurgy," "suppose a certain metal to require 1000° C. for its fusion, it might be subjected to 999° for ever without melting. Just so," he continues, "it may be in the blast furnace with respect to the carburisation of the reduced iron and certain other chemical actions which, moreover, take place with slowness at one temperature and with rapidity at another more elevated. In order to produce these actions in a furnace on cold blast, it is requisite to consume a much larger quantity of coal than in a furnace on hot blast. A few degrees of temperature may make all the difference." The Doctor goes on to explain certain minor causes which may give rise to some saving, but, in the end, he admits that none of the answers which have been given as explanations of the theory of the hot blast are to himself satisfactory, and that a solution of the question is still wanting. Not as explanatory, but as a statement of a probable fact, Dr. Percy reminds us that, inasmuch as for every ton of iron made, a larger quantity of coke is consumed when the furnace is driven with cold than with hot air, it is clear the number of units of heat evolved can have little to do with the matter, and that this being admitted, the inevitable conclusion is that *calorific intensity* must be concerned, and that the temperature of what may be designated as the most active part of the furnace must be higher with the hot blast than with the cold.

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* The temperature of the gases of combustion, leaving the hot-air stoves at the Clarence Works, was found to be about 1400° F. (760° C.), to which has to be added loss from radiation.

It is needless to trouble you with quotations from other authorities, who all appear to agree with this writer, although some of them quote other reasons than those assigned by him in support of the view just stated.

Let us consider how far this idea of increased calorific intensity accords with probability and with fact, and for this purpose it may be well to regard the subject, in the first instance, from the practical point of view.

It will probably be conceded that if the temperature of one furnace were greater than that of another, the fused materials from it, *i.e.*, pig-iron and slag, should show some symptoms of the difference of temperature. Most of the cold-blast iron smelters with whom I have discussed the subject during recent inquiries, and all of whom have also furnaces blown with heated air, appear to consider that the iron from the latter is the more fluid of the two. This, however, may be due to some difference in composition of the metal itself, for they all at the same time admitted that, so far as heat could be estimated by colour, there existed no reason for supposing the temperature of either slag or iron to be lower from a furnace driven by cold than from one supplied with hot blast. In company with our own furnace manager, Mr. Thompson, a gentleman of large experience, who assisted me in my observations, I certainly arrived at the same conclusion.

Again, experience and practice have demonstrated, beyond all question, that the production of different qualities of pig-iron is determined by the temperature of the furnace—No. 1 being obtained when the working is at the hottest; indeed, so established a fact is this, that smelters are pretty well agreed among themselves as to the additional weight of coke which is required to raise their produce each number in the scale. Now this being the case, where, it may be asked, is the authority for supposing that the heat of a hot blast furnace running, say, No. 3 iron, is higher than that of a cold blast furnace producing the same quality? Were the "calorific intensity" greater, as Dr. Percy supposes, one would imagine, from the law just alluded to, a higher quality of metal would be the result, as indeed happens whenever, from any cause, the heat is increased.

It is very true that when a furnace is looked into at the tuyeres, one blown with hot blast exhibits a dazzling white heat, whereas the large amount of cool air poured into a cold blast furnace produces a tuyere which is more or less black; but are we entitled to consider this refrigeration more than local?

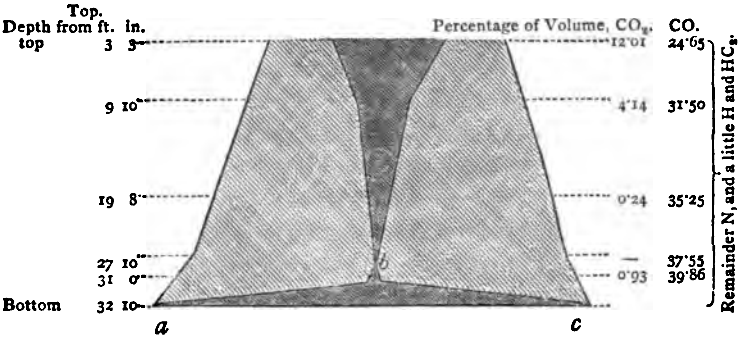
At no portion of the furnace, except at the top, does there exist less reason why the composition of the gases should experience more variation than near the region of fusion; for by this time all chemical change in the ore and flux has been accomplished. Neither is there any portion, with the exception above given, where an average sample is more easily collected, inasmuch as the sectional area of the furnace is much smaller, and its condition generally more uniform than higher up.

Now, the first effect upon the blast on its being admitted into the furnace is the conversion of its oxygen into carbonic acid, and the extent of space in which this change is effected may be accepted as an expression of the intensity of the heat produced in that space. On looking over the analyses of the gases of furnaces, I cannot find any justification for the idea that the oxygen unites more rapidly with carbon in hot than in cold blast furnaces.

The same mode of showing the meaning which is intended to be conveyed has been pursued as when describing the composition of the gases of the furnace, viz., by diagram. The first one shows the carbonic acid and carbonic oxide in a cold blast, and the other in a hot blast furnace, with air heated to 190° C. (374° F.), both at Clerval in France, using charcoal, the analyses being those of Ebelmen.

FIG. 113.

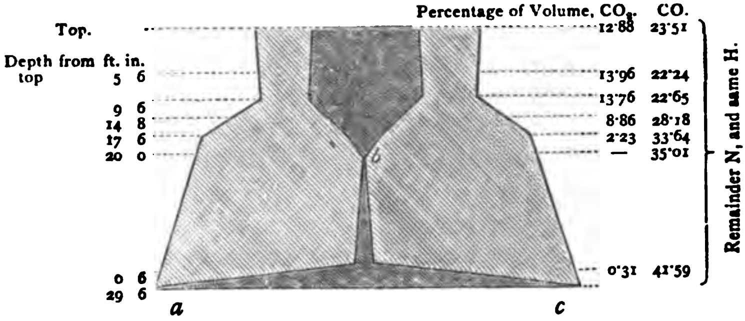
COLD BLAST.



In the diagram Fig. 113, cold blast, the carbon vapour from existing entirely as carbonic acid at the tuyeres, by the time it travels 22 inches, exists only in this form to the extent of 0·93 per cent of the total gases, and, by the time 5 feet from the bottom is reached, there is no longer any carbonic acid present. In other words, the oxygen of the blast has in this space been all converted into carbonic acid, and afterwards changed into carbonic oxide.

In the case of the hot blast furnace, a distance of 3 feet from the bottom shows 0·31 per cent of carbonic acid, and a height of 9½ feet has to be travelled before it disappears; so

FIG. 114.
HOT BLAST.



that, undoubtedly, so far as temperature can be judged of, by the smallness of the space in which perfect oxidation and subsequent reduction to carbonic oxide is effected, the cold blast furnace would appear to be the hotter of the two. Certainly the diagrams in which the relative dimensions of these spaces are expressed by the dark shading in each case comprised within *a*, *b*, *c*, do not exhibit any reason for supposing the temperature of the zone of fusion is higher with the hot blast than that of cold, whereas some grounds have been given to show that the difference, if any, is very trifling.

Permit me to invite your attention, with a view of endeavouring to ascertain whether the mode of action of the hot blast cannot be explained upon different grounds. Before doing so, it may be questioned whether the supposed calorific intensity, suggested by Dr. Percy, as being required for the carburisation of the reduced iron, and some, at least, of the other chemical actions may not be omitted in the enquiry; for, if the views laid down in this paper are correct, most of the chemical changes on the materials have been effected in a much cooler part of the furnace.

It will be recollected that we started upon this enquiry with supposing that the heat from 2 cwts., or thereabouts, of fuel, which we will, for simplicity's sake, assume to be pure carbon, represents the heat thrown into a furnace by means of the blast being heated to 339° C. (650° F.) In practice, we are pretty near the truth in accepting as a fact, that an estimate of the heat developed by the blast on the coke is obtained by considering its oxygen converted into carbonic oxide; for, although at the instant of its admission carbonic acid is generated, this substance is almost as rapidly converted into carbonic oxide by the action of the incandescent coke. But in the hot-air stoves the 2 cwts. of carbon is converted permanently into its highest state of oxidation, and, taking the units of heat as 2221° C. for burning carbon to carbonic oxide, and as 7900° C. for burning carbon to carbonic acid, the 2 cwts. burnt in the stove will represent 7·11 cwts. of carbon burnt in the furnace, or, say, something like 7½ cwts. of coke.

In round numbers, therefore, we may consider 7½ cwts. of our saving of the 10 or 11 cwts. to be accounted for, leaving still 2½ to 3½ cwts. for further investigation.

Now, let us assume that the coke required is 40 cwts. for the ton of cold blast iron, and into the furnace, blast heated to 339° (650° F.) is suddenly introduced, which is, as we have seen, equal in calorific power to 7½ cwts. of coke, so that so far as a mere question of heat is concerned, something like 47½ cwts. of coke is being applied to the production of a ton of metal for which 40 cwts. will suffice.

A common yield of calcined clay ironstone is 40 per cent, so that 50 cwts. are required for a ton, to which has to be added, say, 12 cwts. of limestone. The "burden," then, for one ton of cold blast iron would be—

Coke, 40 cwts.; calcined ironstone, 50 cwts.; limestone, 12 cwts.

But by the addition of the equivalent of 7½ cwts. of coke, these proportions will require a corresponding modification, and a ton of iron will be represented by—heat in blast, equal to 7½ cwts. of coke; coke reduced by this addition of heat in the blast to 32½ cwts.; calcined ironstone and limestone as before, viz., 62 together.

But what is the effect on the furnace itself by such a change in the proportion of its contents. To answer this, let us imagine a furnace with a capacity of 6,000 cubic feet.

The weights of the materials used at the Clarence Works have been carefully ascertained, and, as charged into the furnace, are—

Coke, 0·234 cwt. per cubic foot as contained in the barrow.
Calcined ironstone, 0·624 cwt. per cubic foot as contained in the barrow.
Limestone, 0·706 cwt. per cubic foot as contained in the barrow.

Or, taking the average of the two last together, in the proportions they are used, 0·640 cwt. will represent a cubic foot.

It was further determined that the weight of material in a furnace, before being lighted, was such as to indicate a compression of something like 25 per cent, so that a furnace of 6000 cubic feet would contain 7500 cubic feet of materials as measured in the charging barrows.

By these figures it would appear that such a furnace working on cold blast would contain—

| | |
|---|---|
| Coke | 56 tons. |
| Calcined ironstone and limestone | 87 „ |
| | 143 „ |

but introduce the air heated so as to reduce the coke to about 30 cwts. to the ton of iron, and the furnace would contain of

| | |
|---|---|
| Coke | 50 tons. |
| Calcined ironstone and lime | 103 „ |
| | 153 „ |

Neither of these two sets of figures really represents what is contained in a blast furnace at any one time when filled and in working order. In the case of the hot blast furnace, 103 tons of ironstone and limestone represent twenty-four hours' working, whereas, as is well known, it requires something like thirty-six hours, at the usual rate of driving, to pass the entire contents through such a furnace. The estimate is based on what 7500 cubic feet will contain of cold materials, whereas, when the furnace is in full operation, the coke loses considerably in weight before it reaches the tuyeres, and the other materials become greatly condensed as they approach the seat of fusion.

It would be almost impossible to ascertain to what extent these figures become modified by the action of the heat when the furnace is in blast, or what the effect of the altered proportions would be on the temperature of the ascending gases.

To obtain the exact figures for this, we ought to have the specific heat of all the various materials in the furnace ; and it would be equally difficult to ascertain what the specific heats of the contents of the furnace really are during the process of smelting, as it is difficult to ascertain the temperature of the different portions of the interior of a furnace.

Schinz has shown, in a recent work, how rapidly the specific heats increase with rise of temperature. According to his researches, the following list shows the change of specific heat with elevation of temperature :—

| At | Coke. | Limestone. | Lime. | Iron Ore. | Iron. | Slag. |
|---|---|---|---|---|---|---|
| 100° C. | 0·157 | 0·166 | 0·216 | 0·171 | — | — |
| 250° C. | 0·186 | 0·273 | 0·233 | 0·185 | — | — |
| 500° C. | 0·234 | 0·451 | 0·260 | 0·209 | — | — |
| 750° C. | 0·283 | 0·628 | 0·287 | 0·233 | — | — |
| 1000° C. | 0·330 | — | 0·314 | 0·257 | 0·152 | 0·259 |
| 1500° C. | 0·428 | — | — | — | 0·184 | 0·322 |
| 2000° C. | 0·525 | — | — | — | 0·216 | 0·384 |

Without any information to guide us as to the exact condition, chemically speaking, of the contents of the furnace, or the rate at which they lose weight and acquire heat, it would be mere guess-work to estimate the number of units of heat intercepted by the materials under treatment.

That the withdrawal of so many cubic feet of coke, and the substitution of substances nearly three times its weight, and with a mean specific heat rather higher than that of the coke itself, must permit a more perfect absorption of heat from the ascending current of gas is obvious.

In illustration of this, an experiment made at the Clarence Works may be quoted. Through a pipe 12 inches in diameter and 6 feet high, a given volume of air, heated to the melting point of lead, was passed.

The pipe was filled with coke properly dried, and afterwards with calcined ironstone, and then limestone. The power of intercepting heat from the same volume of air is expressed by the following numbers :—

| | |
|---|---|
| For coke . . . . . . . . . . | 100 |
| ,, calcined ironstone . . . . . | 188 |
| ,, limestone . . . . . . . . . | 144 |

Looking at the complicated nature of the problem, it appears as if there is no alternative left but to ascertain the actual amount of heat carried off in the escaping gases, after they have performed their work in the furnace, and this, during a whole day, was done most carefully at the Cyfarthfa works at a hot and cold blast furnace.

The mode of procedure was as follows:—To ascertain the temperature of the gases, a pyrometer, made by Kraus, of Paris, was plunged into the gases where they left the furnace, and occasionally an observation was taken by means of apparatus supplied by Mr. C. W. Siemens, consisting of a copper cylinder, which, being immersed in the gases, indicated their temperature by the amount of heat it conferred on a given quantity of water. Both of these instruments are open to the objection of requiring time, so that in cases where the temperature is constantly changing, neither gives results which are strictly correct. To obviate this difficulty, I constructed another pyrometer, which, though liable to some irregularity, possesses the advantage of being much more immediate in its indications. It was simply a copper tube, about 3 feet long and 1 inch diameter, closed at the lower end and screwed into a Bourdon's pressure gauge, so that it was hermetically tight. The expansion of the air by increasing the pressure enabled me to read off minute variations almost the instant they took place.

To estimate with strict correctness the heat carried off with the gases, an analysis of samples extending over some hours would have been required, both for the purpose of calculating the quantity and the specific heat. This was not in my power to do, and in consequence the composition of the escaping gases has been assumed as being the same as those given off by a furnace of nearly the same dimensions at the Clarence works. It is believed that any difference in respect to this will not seriously affect the results of the calculation.

The gases were assumed to contain, according to weight—

$$CO_2,\ 9;\ CO,\ 32;\ N,\ 59 = 100.$$

| | | | | | |
|---|---|---|---|---|---|
| C in $CO_2$ | = 2·45 | C in CO | = 13·71 | = Total C | 16·16 |
| O ,, | = 6·55 | O ,, | = 18·29 | ,, O | 24·84 |
| Total $CO_2$ | 9·00 | Total CO | 32·00 | Total C and O | 41·00 |

| | | | | |
|---|---|---|---|---|
| Coke used per ton of iron was— | | cwts. | 34·80 | |
| Deduct ash . . . . . | 5 per cent | 1·74 | | |
| $HO$ (weather was wet) . | 5 „ | 1·74 | | |
| For combination with iron | | 0·74 | | |
| | | | 4·22 | 30·58 |
| Carbon in limestone. . . . . . . . . . . . | | | | 2·12 |
| Total carbon going off in gases . . . . | | | | 32·70 |

With the composition of the gases given above this carbon will be volatilised in the following state as—

| | | |
|---|---|---|
| $CO_2$ . . | 4·96 cwts. | |
| $CO$ . . | 27·74 „ | |
| | | 32·70 |

| | | | | |
|---|---|---|---|---|
| C | 4·96 | for conversion to $CO_2$ requires | O | 13·23 |
| C | 27·74 | „ $CO$ „ | O | 36·99 |
| | 32·70 | Total O . . . . | | 50·22 |

But in the materials themselves there is—

| | | |
|---|---|---|
| O in the $CO_2$ of the limestone (viz., 17·66 cwts. per ton of iron) = . . | 5·65 cwts. | |
| O in 48·43 ores (part of Fe being as $FeO$) . . . . . . . . . . . . . . | 7·35 „ | |
| | | 13·00 |
| Leaving to be supplied by blast of O . . | | 37·22 |

The total weight, then, of the gases would be—

| | |
|---|---|
| Carbon . . . . . . . . . . . . . . | 32·70 cwts. |
| Oxygen . . . . . . . . . . . . . . | 50·22 „ |
| Nitrogen accompanying 37·22 O of blast | 124·60 „ |
| Water in coke, 1·74 ; water in ore, 2·19 . | 3·93 „ |
| | 211·45 „ |

We have as total weight of gases—

| | | |
|---|---|---|
| C, 4·96 + O, 13·23 = $CO_2$, | 18·19 cwts. | |
| C, 27·74 + O, 36·99 = $CO$, | 64·73 „ | |
| N . . . . . . . . . . | 124·60 „ | |
| $HO$ . . . . . . . . . | 3·93 „ | |
| | | = 211·45 |

The mean temperature of these gases as they left the furnace was ascertained to be 445° C. (833 F.)

By multiplying these weights by their various specific heats and temperature we have—

$$\left.\begin{array}{lrcrcr} \mathrm{CO_2} \;.\;.\;.\;.\;. & 18{\cdot}19 & \times & 0{\cdot}212 & \times & 445^\circ \\ \mathrm{CO}\;.\;.\;.\;.\;.\;. & 64{\cdot}73 & \times & 0{\cdot}288 & \times & 445^\circ \\ \mathrm{N}\;.\;.\;.\;.\;.\;. & 124{\cdot}60 & \times & 0{\cdot}275 & \times & 445^\circ \\ \mathrm{HO}.\;.\;.\;.\;. & 3{\cdot}93 & \times & 1{\cdot}000 & \times & 445^\circ \end{array}\right\} = 26967$$

And this divided by 2221 units of heat, burning C to CO, gives 12·16 cwts. carbon, or, say, 12·76 dry coke, as going off with the escaping gases from the cold blast furnace.

In the case of the hot blast furnace, with air heated to 320° C. (608° F.), the calculations stand thus—

| | | |
|---|---|---|
| Coke used per ton of iron was— | | 26·74 cwts. |
| Deduct ash in coke 5 per cent | 1·33 | |
| Ditto HO in do. ,, | 1·33 | |
| Ditto C combined with iron | 0·74 | |
| | | 3·40 ,, |
| | | 23·34 |

Lime was added in its caustic state, hence there is no carbon to include from this source.

Upon the same basis as the previous calculation the carbon will be given off in the gases as—

| | | |
|---|---|---|
| $CO_2$ . . . | 3·53 cwts. | |
| CO . . . . | 19·81 ,, | |
| | | 23·34 |

| | | |
|---|---|---|
| C 3·53 | requires for conversion to $CO_2$ — of O | 9·41 |
| C 19·81 | ,, ,, ,, CO — of O | 26·41 |
| 23·34 | | 35·82 |
| | Less O in the ores, Fe partly existing as FeO | 8·12 |
| | Leaving O to be supplied by blast . . . . | 27·70 |

Total weight of gases will be—

| | | |
|---|---|---|
| Carbon . . . . . . . . . . | 23·34 | |
| Oxygen . . . . . . . . . | 35·82 | |
| Nitrogen accompanying 27·70 O | 92·73 | |
| Water in coke, 1·33, and ore, 1·73 | 3·06 | |
| | | 154·95 cwts. |

The mean temperature of these gases was ascertained to be 477° C. (891° F.), and their estimated constitution would be as follows:—

| | | |
|---|---|---|
| C, 3·53 + O, 9·41 = $CO_2$ | 12·94 | |
| C, 19·81 + O, 26·41 = CO | 46·22 | |
| N . . . . . . . . . . . | 92·73 | |
| HO . . . . . . . . . . | 3·06 | |
| | | 154·95 cwts. |

By multiplying these weights by temperature and specific heats we have—

$$\left.\begin{array}{llr} CO_2 & \ldots & 12{\cdot}94 \times 0{\cdot}212 \\ CO & \ldots & 46{\cdot}22 \times 0{\cdot}288 \\ N & \ldots & 92{\cdot}73 \times 0{\cdot}275 \\ HO & \ldots & 3{\cdot}06 \times 1{\cdot}000 \end{array}\right\} \times 477^{\circ} = 21274.$$[*]

This divided by 2221 = 9·57 cwts. carbon, or dry coke, 10·04.

Now, as the heat escaping from the cold blast furnace represented in coke for each ton of iron is . . 12·76 cwts.
Whereas with that on hot blast it is only . . 10·04 „

It follows there is escaping from the cold blast furnace, above that going off from the hot, heat equal to coke . . . . . . . . . . 2·72 „

We have in consequence the total saving of coke as follows—

1st. By use of blast heated as formerly stated 7·50 cwts.
2nd. By diminution of loss of heat in the escaping gases . . . . . . . . . 2·72 „
10·22 „

Which accords with the saving given as effected by the use of 5 cwts. of coal for heating the air, of which only about 2 cwts. were really available.

It may be interesting to compare the duty of the two different furnaces, by deducting the heat carried off by the waste gases and that required for melting the slag, which latter varies of course in amount according to the minerals used. In estimating the fuel required for this latter object, Vathaire's figures of 550 units per kilogramme of slag is accepted as the basis of calculation.

The hot blast furnace in Wales stands thus, making white iron—

---

[*] The fact that very different materials were employed in the two furnaces which were examined, prevents a strict comparison between their respective temperatures being instituted. All that can be done is to ascertain in both cases the actual amount of heat escaping.

| | | |
|---|---|---|
| Coke used per ton of iron . . . . . . | | 26·74 cwts. |
| Heat contained in 120 cwts. of blast at 320° $\frac{120 \times 0{\cdot}287 \times 320}{2221}$ = carbon 4·95 = coke | | 5·16 ,, |
| | | 31·90 ,, |
| Heat escaping with gases— | | |
| As formerly calculated = carbon | 9·57 | |
| Melting 23 cwts. slag, do. . . | 5·70 | |
| | 15·27 = coke | 16·04 cwts. |
| Leaving for reduction and fusion of metal, loss from radiation, &c. . . . . . . . . . . | | 15·86 ,, |

The cold blast furnace in Wales exhibits the following results, also producing white iron:—

| | | |
|---|---|---|
| Coke used per ton of iron as formerly given . . | | 34·80 |
| Heat 37° C. (100° F.) contained in blast produced by compression in blast engine $162 \times 0{\cdot}287 \times 37 \div 2221$. . . . . . . | | 0·78 |
| | | 35·58 |
| Heat escaping with gases as formerly estimated = carbon . . . . . . . . | 12·16 | |
| Melting 30 cwts. of slag, do. | 7·43 | |
| | 19·59 = coke | 20·49 |
| Leaving for reduction and fusion of metal, loss from radiation, &c., . . . . . . . | | 15·09* |

Let us test by another method this mode of calculation. Suppose two furnaces of such dimensions, and using such a kind of mineral that for producing the same quality of iron the consumption was 30 cwts. per ton of iron for hot blast, and 40 cwts. for cold blast.

| | |
|---|---|
| For the hot blast furnace we have coke . . | 30 cwts. |
| And with the air at 800° F. (426° C.) there will be heat equal in coke to about . . . | 8 ,, |
| | 38 ,, |
| Deduct for heat carried off by gases something like. . . . . . . . . . . . . | 9 ,, |
| Leaving for reducing iron, fusing it and the slag, loss by radiation, &c., . . . . . . . | 29 ,, |

---

* The iron from this furnace was somewhat inferior in quality to that from the hot blast furnace, which may account for the difference between 15·86 and 15·09 cwts.

| | |
|---|---|
| In the case of the cold blast furnaces the coke is taken at | 40 cwts. |
| Added with blast by compression heat equal in coke to about | 1 ,, |
| | 41 ,, |
| Carried off by gases, say | 12 ,, |
| Leaving for reduction of iron, &c. | 29 ,, |

Imagine, now, that instead of introducing with the blast the heat of 8 cwts. of coke, an equivalent of which and more escapes at the top of a low furnace, measures were taken to prevent this source of loss, which is something like 12 cwts. of coke in the case of one blown with cold air. This could be done by adding something to the height, and thus cause the highly heated gases to yield up the greater portion of their heat to the additional materials contained in this increase of size. If the temperature of the gases from a cold blast furnace was such that it represented 2 instead of 12 cwts. of coke, a clear saving of 10 cwts. would be effected by the change, or the 40 cwts. of coke per ton of iron might be reduced to 30 cwts., for we would have 30 + 1 cwt. for heat conveyed in

| | |
|---|---|
| The blast = | 31 |
| Less carried off in gases | 2 |
| Leaving for actual furnace work | 29 |

Now, this is exactly what has been done at the Lilleshall Iron Works. Furnaces formerly 50 feet high have been raised to 71 feet in height, and the consequence has been that those of the latter dimensions, blown with cold air are making iron for the same quantity of fuel used by hot blast furnaces of the former size, viz., 50 feet.

Unfortunately, the mode of construction is not such as to permit a verification of the actual heat going away from each; but there is little doubt that, were this done, we should see that the sum of heat introduced by coke and blast, *minus* that escaping, gives in both cases the same result to represent work actually performed.

Of course, all this forms no argument against the economy of the hot blast; because from furnaces of 48 and 50 feet, blown with heated air, something like 10 cwts. of coke escapes in the gases—a loss which has been reduced to something under one-half of this by adding 30 feet to their height; indeed, it was with hot blast furnaces that the great advantage of increased height was first demonstrated.

It is almost needless to say that there are, in connection with the blast furnace, many other questions of a highly interesting nature in a scientific point of view, as well as most important regarded as matters of practical economy, which the length of time I have occupied your attention forbids me to enter upon. Such is the actual heat given off by the combustion of the fuel compared with the real effect produced, together with many others. I have, instead of going into these, preferred submitting for your consideration views connected with the subject of iron smelting, which, so far as I know, differ in some respects from those previously expressed.

## THE SCHINZ BLAST FURNACE.*

The chief and vexed question in the metallurgy of iron has lately been investigated and pondered over by one of the scientific authorities on the Continent, Herr C. Schinz, who has published an account of his experiments concerning principally the heat and the reduction of materials in blast furnaces, and has ventured to recommend a new system of treating the ores, based upon the result of his researches. It is an acknowledged fact that oxide of iron is easily reduced if a current of hydrogen be passed over it at red heat. A current of carbonic oxide would be equally serviceable, and to the efficacy of this agent the inventor and patentee has directed special attention. By partial elimination of nitrogen, through the means of an artificial supply of carbonic oxide, he endeavours to show that extensive improvements in the production of iron can be effected. We will put before our readers his arguments and the application to the kind of blast furnace the use of which he advocates.

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* The Engineer, Nos. 697 and 699, May 7 and 21, 1869.

If a volume of carbonic acid is passed over coal or any other substance containing carbon at red heat, half the volume of carbon is taken up, and instead of carbonic acid we obtain two volumes of carbonic oxide. Burning these in the presence of atmospheric air, we obtain two volumes of carbonic acid, and with them 3·771 volumes of nitrogen set free. These products, brought again in contact with hot coal, form four volumes of carbonic oxide, together with 3·771 volumes of nitrogen. Now it is evident from these data, since the number of volumes of carbonic oxide is doubled, while that of nitrogen remains unchanged, that the former is increased from 34·65 per cent to 51·47 per cent.

Regarding the question of proportionate expense in producing carbonic oxide artificially, as we may call it, Herr Schinz speaks with much confidence, and after a short sketch of his investigations with regard to the theory of blast furnaces, we will give his proposals and the plan upon which he means to work.

His theories and experiments, resulting in a considerable and interesting amount of carefully compiled tables, open a vast field of argument, which must tend to advance the embryo of a science so universally important and yet treated in so stepfatherly a manner.

By the process of burning we understand the chemical combination of the oxygen in the air with the carbon and the hydrogen contained in the fuel. The products, the evolved heat, and its intensity, are not always the same; they change under circumstances which we have to consider. The influences at work are, the number of the points of contact which the fuel offers to a given volume of air in a unit of time, the height of temperature in the hearth, the purity and dryness of the air, and the pressure. The heat produced is 8000 thermal units, if only carbonic acid is formed, per unit (weight) of carbon, and 2400 thermal units if this carbon burns to carbonic oxide.

The free hydrogen in the fuel at a sufficiently high temperature forms always water evolving 3400 thermal units per unit (weight). It is to be observed that, if the temperature be too low, carburetted hydrogen is produced instead. The intensity of the heat depends upon the admixture of bodies which take no part in the combustion, such as nitrogen and steam; secondly, upon the quantity of the actually developed heat; and, lastly, upon the pressure to which the products are subjected. With regard to the points of contact, the author considers the recent American method of blowing the fuel into the furnace an extreme and expensive measure, and recommends instead of it the conversion of fuel into operative gases. The difficulty with the former process of finding the proper amount of air requisite for the combustion might, according to his method, be easily overcome. Experiments made with pieces of fuel cut to certain dimensions resulted in showing, (1) that a perfect combustion depends upon the contact surface in proportion to the rapidity of the blast; (2) that per square metre that velocity ought to be 0·39 metre; (3) that at a decreased velocity combustible gases will appear in the products; (4) that at a velocity of 0·39* metre nearly all the carbon is turned into carbonic oxide. The pores of the various kinds of fuel, and the point of attack which they offer, have not been numerically considered in the above. Certain modifications, consequently, will be necessary where charcoal, anthracite, or pit coal is used instead of coke. Charcoal is the most porous of the four; anthracite, which, when experimented upon, allows considerably more air to waste, thereby proves to be the denser material.

At a temperature of 500°, the surface of contact must be very large to bring one-third of the carbon to carbonic oxide, while the reduction and formation of carbonic acid at a high temperature require hardly any contact surface at all, the reasons for which circumstance will be shown further down. According to analysis in a trial on 10·47 square metres with one cube metre of air, the amount of carbonic acid was 7—12 per cent, on 21—23 per cent of carbonic oxide. Although the air contained in the fuel itself had some influence on the experiments, yet it may be accepted with a fair amount of probability that, in blast furnaces, on one cubic metre of air per second one square metre of contact surface is required for the formation of carbonic acid, and twelve square metres for the reduction.

---

* This figure is given 0·09 in the documents before us, which evidently is a misprint.

Where the horizontal section of the hearth and the height of the layer of fuel above the grate are known, the calculation of the contact surface is an easy task when the pieces are of equal size.

The space S between the pieces of fuel is, for one and the same surface, always the same, be the pieces large or small.

$$\text{For } S = (1 - n^2)\, d^2\, \pi$$

($n^3$ expresses the number of pieces to a cube metre, $d$ the diameter of each piece, and $l$ the side of the cube metre).

If $d$, $f$, $i$, be thirty millimetres, we find according to the formula $n^3 = \left(\frac{l}{d}\right)^3$.

$$n^3 = \left(\frac{1000}{30}\right)^3 = 37038 \text{ pieces}$$

and

$$n^2 = \left(\frac{l}{d}\right)^2 = 1111$$

Consequently the space between the pieces

$$1 - \left(1111 \cdot \frac{0{\cdot}03^2 \cdot \pi}{4}\right) = 0{\cdot}2146 \text{ square metres.}$$

The influence of the season upon the process is evident from the following data :—

One cubic metre of atmospheric air contains, when saturated with vapour :—At 0° C. temperature, 0·0052 kilo. vapour ; at 5°, 0·0072 ; at 10°, 0·0095 ; at 15°, 0·0128 ; at 20°, 0·0168 ; at 25°, 0·0220 ; at 30°, 0·0285 ; at 35°, 0·0370 kilo. vapour.

This table shows that the amount of humidity in the air increases with the temperature. It is also experienced that, in the winter time, the fuel can carry more than in the summer time, which herein must find its explanation. Nor is this circumstance a trifling one, since we shall be able to demonstrate that nearly one-fifth of the otherwise-produced heat may thus be absorbed by the hydrogen liberated from the oxygen of the water. Suppose 0·037 kilo. of the latter to be contained in the cube metre of the blast—not an unlikely thing to occur where the blast and steam engines are in the same room—and suppose 1000 kilos. of coke, containing 75 per cent of carbon, to be consumed in the furnace, then $\frac{750}{3600}$ = 0·208333 kilo. of carbon will be burnt. They require 0·27777 of oxygen, corresponding to 0·96112 kilo., or 0·70682 cube metre of atmospheric air for their combustion. At 0·037 kilo. per cube metre, as mentioned above, there would be 0·02615 kilo. of steam contained in that amount of air. Hence we have 0·0029055 kilo. of hydrogen, which, during the generation of carbonic oxide, absorbs 0·0029055 × 34000 = 98·789 thermal units, while the 0·208333 of carbon burnt to carbonic oxide gives but 0·208333 × 24000 = 499·99 thermal units. Consequently, instead of 0·48611 kilo. of carbonic oxide and 0·68335 kilo. of nitrogen, whose specific heat is 0·120510 × 0·166740 = 0·28725, we have 0·48611 kilo. of carbonic oxide, 0·0029 kilo. of hydrogen, and 0·60683 kilo. of nitrogen, whose specific heat is 0·120510 + 0·009892 + 0·148060 = 0·278462, from which we calculate the temperature with a dry blast to be $\frac{499·99}{0·28725}$ = 1740°, and, with a humid one, only $\frac{401·2}{0·278462}$ = 1441°. Another important feature is presented by the influence of the blast itself. The temperature of the products of combustion depends upon the volume, since the generated heat is distributed around; if these products are compressed the temperature must necessarily increase, and bring about a more rapid consumption of carbon, and hence a quicker descent. The effect of this is a direct reduction of the oxides, silica, &c., in the ores by solid carbon. In most instances, however, the amount of pressure cannot be regulated or even ascertained, since it depends, to a great extent, upon the resistance of the smelting pile. A strong blast bringing about a quicker descent is injurious to the quality of the metal for two distinct reasons. In the first instance, the gases generated for the reduction of the ores are breaking their way through wide channels without permeating the mass in minute windings. The smelting at the base creates a hollow into which the unreduced ores fall in a mass, thereby retarding the functions of the furnace. Even if the quantity be too small to effect a serious disaster, yet by the smelting of the ores in the hearth there is left but little chance for the reduction; but whatever of direct reduction may take place is not a desirable occurrence, since heat is thereby absorbed to such an extent that, without speedy assistance, stagnation is not an improbable thing to ensue. Secondly, the crude iron itself may begin to burn, which will increase the temperature considerably in the whole of the internal cavity of the furnace, 1276 thermal units per kilo. being freed. The danger in this instance is not so much the want of means for mending the defect as the tendency to do too much by resorting to extreme measures, which, while curing the one, bring about another and a new disturbance.

A consideration of the quantity and intensity of heat will bring us back to the main point of the invention.

One kilo. of carbon requires for its combustion to carbonic acid ($6 : 1 = 16 : x$).

$$2{\cdot}666 \text{ kilos.} = \frac{2{\cdot}66}{1{\cdot}43028} = 1{\cdot}8654$$

cube metres of oxygen, with which we find (according to $1{\cdot}8654 : 20{\cdot}96 = 70{\cdot}04 : x$) 7·0309 cubic metres = 8·8347 kilos. of nitrogen, provided that, as usually, air is used for the blast. One kilo. of carbon burned to carbonic acid evolves 8000 thermal units. The products of combustion consist of—1 carbon + 2·66, oxygen = 3·66 kilos. of carbonic acid, and 12·365 kilos. of nitrogen. Now, the specific heat of these products is—carbonic acid, $3{\cdot}6 \times 0{\cdot}2164 = 0{\cdot}79344$; nitrogen, $8{\cdot}8347 \times 0{\cdot}2440 = 2{\cdot}1557$; together $= 2{\cdot}94914$.

Dividing this specific heat into the produced heat, we obtain the temperature generated by the combustion, viz., $\frac{8000}{2{\cdot}94914} = 2712{\cdot}7^\circ$ C., which also expresses the intensity of the fire.

If pure oxygen were used instead of air, the quantity evolved would remain the same, but the intensity would increase, since no more nitrogen would encumber the volume of the gases. The intensity would be $\frac{8000}{0{\cdot}79344} = 10082{\cdot}8^\circ$ C., or nearly four times as great. The use of pure oxygen, however, is at present out of the question on account of the expense involved; and hence we must put aside the idea of getting rid of nitrogen altogether; but we might eliminate part of it, and this the patentee means to effect by burning pure carbonic oxide in air, and conducting the products thereby gained over solid carbon, where they are reduced again to carbonic oxide, which then is re-burned. Now, 0·5 kilo. of carbon correspond to 1·1666 kilos. of carbonic oxide, for the combustion of which we require 0·6666 kilo. of oxygen; they being obtained from the atmosphere, introduce 2·2087 of nitrogen. The thus-formed 1·8333 kilos. of carbonic acid give, by taking up 0·5 kilo. of carbon, 2·3333 kilos. of carbonic oxide, which require 1·33 kilos. of oxygen and 4·4174 kilos. of nitrogen, the products at last containing 3·6666 kilos. of carbonic acid, 6·6261 kilos. of nitrogen, whose specific heat is 3·6666 × 0·2164 = 0·79344, and 6·6261 × 0·2440 = 1·61680; together, 2·41044.

But if the originally burnt 1·1666 kilos. of carbonic oxide are cold, the heat produced is only that which corresponds to the lastly-obtained carbonic oxide, viz., 2·3333 kilos. × 2400 = 5599·9 thermal units, for the heat generated by the combustion of 1·1666 kilos. of carbonic oxide is all used again, in order to reduce carbonic acid to carbonic oxide. By performing the same operation as above, we find a temperature of only $\frac{5599{\cdot}9}{2{\cdot}41024}$ = 2323° C. That is, less than we obtained by a direct combustion, which showed 2712° C. If, however—and here we touch upon another point—we pre-heat the carbonic oxide and all the requisite air to 500°, we add thereby 1169 thermal units, and, consequently, $\frac{5599{\cdot}9+1169{\cdot}8}{2{\cdot}41024}$ = 2808° C.

Now, the surplus of 96° seems to be hardly worth the trouble which these operations must cause. Yet there are cases—for instance, the melting of steel—where such a surplus is of consequence, not only on account of the increased temperature, but also on account of the circumstance that the volumes of the products of combustion at the respective temperatures stand in a proportion of 97·3 : 80·6, and that hence, under equal circumstances, an acceleration can be imparted to the products of combustion exceeding the ordinary one by one-fifth. Besides, it has to be considered that the relative proportion between nitrogen and carbonic oxide is of importance to the process of reduction in blast furnaces. When two substances unite chemically, heat is liberated, but the quantity of this heat depends upon the proportion in which they unite, as well as their nature. A unit (weight) of carbon evolves 2400 thermal units if it burns to carbonic oxide; but if it burns to carbonic acid, the quantity generated is 8000 thermal units. Caustic lime, slaked to a hydrate, when subjected to a rapid stream of carbonic acid under water, so as to saturate the hydrate with carbonic acid, offers a ready opportunity for ascertaining the combination heat between lime and carbonic acid, which the author found to be 197·1 thermal units to the unit (weight) of lime.

In blast furnaces, there are five cases in which this particular heat has to be considered—(1) at the combustion of carbon to carbonic acid; (2) at the reduction of carbonic acid to carbonic oxide; (3) at the decomposition of water which is contained in the blast; (4) at the decomposition of carbonate of lime; (5) at the reduction of oxide of iron by coal.

In the first instance the value is positive, that is, the coal burnt evolves for each unit (weight) 8000 thermal units; in the three other cases the values are negative, that is, we have no more to calculate how much heat is produced, but how much is absorbed. In the second instance, the carbonic acid changing into carbonic oxide takes up as much carbon as it contains already; this added carbon needs 2400 thermal units for its evaporation, and the original 8000 thermal units are thereby decreased to 5600 thermal units. The blast is never free from steam, each unit (weight) of which, being decomposed when coming in contact with the heated coal, must bring as much heat to absorption as the 0·111 of hydrogen, which produced it, would have given by combustion; that is, 34000 × 0·1111 = 3778 thermal units. The separation of 0·56 of lime from 0·44 of carbonic acid (Ad. 4), produces an absorption of 0·56 × 197·1 = 110·376 thermal units per unit (weight) of carbonate of lime = 251 per unit of carbonic acid; (Ad. 5), if imperfectly reduced ores get into a temperature where the peroxide of iron joins the scoriæ, forming a kind of paste, the pieces of coal will be surrounded by that paste, and hence a direct reduction by solid carbon take place. One unit of peroxide of iron contains 0·2222 of oxygen, hence 0·387639 units of carbonic oxide are formed, and they contain 0·166131 of carbon, which bring 0·166131 × 2400 = 398·7 thermal units to absorption. This last instance is one which is of great import, although it has hitherto been but hinted at by Ebelmen. The decomposition of chemical substances at high temperatures, although known of old, has, by the recent researches of Sainte-Claire Deville, received an explanation. All compound bodies will separate if we can restore the latent heat to each element, and at the same time separate the molecules or atoms beyond their powers of cohesion. Deville has shown that water, as well as carbonic oxide and acid, can be thus separated into its elements. The reason why success did not attend former trials lay in the way in which those elements were treated after their separation. If allowed to cool gradually, their affinity returns, and there is no more chance for analysis; but suddenly cooled, carbon, hydrogen, and oxygen will each separately appear. Especial interest attaches to the compositions of carbon with hydrogen, and the experiments of Cailletet prove that, in the hearth, carbon and oxygen are principally to be found separate. These trials, the particulars of which we must here omit, explain completely the influence of the temperature at a reduction of carbonic acid to carbonic oxide, for besides the absorption of latent or combination heat of carbonic oxide, which must necessarily take place, the otherwise requisite surface of contact must, as we have previously found, become equal to zero if the temperature be sufficiently high to vapourise the carbon. Now we have to consider the almost universally accepted opinion of practical men, viz., that the working of a blast furnace is the more profitable the higher the temperature in the hearth, which Herr Schinz is not inclined to endorse. There are certain points which seem decidedly in favour of the established theory. At a sufficiently high temperature it might happen that carbon would vapourise in a larger proportion than would correspond with the carbonic oxide, and in that case there would be a larger quantity of carbon for the reduction of the ores. Moreover, according to Ebelmen, there is always a surplus of carbon in the gases which could not have been generated by their combustion with air. The circumstance, also, that this surplus is accompanied by a corresponding surplus of oxygen, which cannot have belonged to the air originally, would not appear contrary to the opinion that this oxygen is derived from the reduction of the oxide of iron in the ores, and which passed off as soon as carbon came in contact with them. The wonderful, yet hitherto unexplained, effect of the hot blast might likewise be looked upon as favourable to the vapourisation of carbon. But, plausible as such a supposition of a surplus of gaseous carbon may appear, Herr Schinz rejects it on the following grounds:—

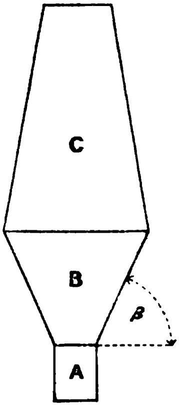
(1). If all means for increasing the temperature in the furnace be employed, such as pressure and heat of blast, dry air, &c., yet immediately above the point where this high temperature is generated by formation of carbonic acid, by reduction of the same, or, if you will, by the vapourisation of carbon, there is so much heat absorbed that the temperature sinks nearly to one-half of the original one, so that the last-gained temperature is but a trifle above that which would be obtained without the application of any heating media whatever. Hence it is incredible that carbon should remain vapourised in great quantities, and hence the effect of these media is reduced to a diminution of the zone or the space in which the formation of carbonic acid and the reduction thereof, or the vapourising of carbon takes place, whereby, indeed, the active space above the boshes is somewhat, but not greatly, increased.

(2). The pre-heating of the blast may be employed as a means either for the saving of fuel or for the quickening of the process. In the first case, the temperature is not increased, and the saving is in proportion to the quantity of heat given to the blast by pre-heating. But if hot blast is used without decreasing the amount of fuel in proportion, the temperature then will be elevated, not only in the hearth, but also in the whole of the internal cavity of the furnace. The consequence is that the ores get faster into a region the temperature of which is sufficient to bring about the paste-like mixture of scoriac material and some peroxide of iron. The reduction of the latter can, after that, no more be effected, either by carbon vapours or by carbonic oxide, solid carbon enveloped in the descending paste being the only available agent.

(3). The reduction of the ore by the means of solid carbon must be regarded as an explanation of the effect of the increased temperature, which is, by far, more consistent with facts, and which thereby overturns the opinion of a vapourisation of the carbon beyond the proportion existing in the carbonic oxide. With regard to the cementing process, there is something to be said which hitherto has not found an explanation. If, as the last experiments of Cailletet show, at a temperature of 581·8°, 2·905 per cent carbon, as a gas, can exist free in the products of combustion, it is evident that the iron in the cementing furnace is continually exposed to an atmosphere containing quantities of carbon in a state favourable to a combination with the metal.

According to Wepfer's experiments, a lining or mantle of coals is formed somewhere about the boshes during the descent of the charges, commencing at the hearth. This lining in time forms a certain resting place, through which the movable materials will find their way to the hearth. During their descent, in consequence of the enlarging of the furnace, they will assume a convex surface, which lower down passes into the straight line, and at last becomes concave. Although slightly, yet the tendency of the ores to push the lighter cokes to the edge is easily perceived. According to Wepfer's studies, in the instance of the Königsbron furnace, the velocity of the descent decreases from the crater to the boshes, from whence it increases again, and in the hearth assumes almost the same which it had 7 or 8 feet below the burden. Near the sides the results are different; the velocity decreases to a depth from 8 to 9 feet also, but slower than in the middle, whereby the convex curves are produced. From thence the descent is quicker at the sides than in the middle, which must necessarily change the convex curve into a straight line, and after that give to the masses a conical or funnel-like shape. The volume of the burdens continually decreases during the descent, which may be explained first by the settling of the materials on account of the pressure of the smelting pile above it; and, secondly, from the using up of the coal either for reduction or for the carbonising of the iron. The displacement of the ores might be explained by the difference in the specific gravities of the same, and of the coals, and, moreover, by the opportunities offered to the smaller pieces of the ore for finding their way through the spaces left between the larger coals. In every apparatus for combustion the fuel forms a more or less considerable resistance to the currents of air and gases. An exact measurement of this resistance is impracticable on account of the inequality of the size of the pieces. The resistance which the blast finds consists, first, in the friction on the walls of the channels through which it is forced; secondly, in the change of the direction of the current of the gases round the various pieces; and, lastly, in the expansion and contraction of the same while passing from smaller to larger, and from larger to smaller channels. In order to move a gas a certain power is required. This power is either gained by a pressure from the blast cylinder or by aspiration by means of a chimney. The obstacles thrown in the way of the blast must very strongly influence the form of blast furnaces. There seems but one point on which practical men are agreed, viz., that wide furnaces are preferable to small ones for the production of *affinir* iron, while narrow ones produce better material for casting purposes. Scheerer attempts to explain this by saying that, in the wide furnace, the products of combustion push upon the ores with less force than in the narrow ones, but since the larger section of the furnace brings about a larger contact surface of the smelting material, such an explanation cannot be considered as valid. It is generally supposed that the wide furnace especially serves to moderate the temperature, and that a moderate temperature is a condition for the production of *affinir* iron. Herr Schinz, however, denies this assumption, and endeavours to show that the production of *affinir* iron—that is, crude iron which is poor in carbon—is to be ascribed to the incomplete reduction of the ores in the reduction zone, and a posterior liberation of iron from the scoriæ by solid carbon. The only true cause why the furnace is more appropriate for the production of *affinir* iron may be that the scoriæ containing iron and coal can no more spread about to the walls, and must hence descend slower into the hearth, above which they must find a larger section, thus giving the solid carbon more time for its action on the peroxide of iron. This view is substantiated by the fact that the layer of scoriæ above the hearth is always darker just after the slag has been drawn off. But this layer becomes lighter the longer it remains exposed to the high temperature in that place. The traditional form of furnaces is as in Fig. 115, where A is the hearth, B the boshes, and C the internal cavity of the furnace. The angle, $\beta$, is the angle of the boshes.

FIG. 115.



Several metallurgists ascribe to the latter an important influence. K. A. Weniger says that at an angle of 25°, 45°, 55°, and 65° the consumption of fuel is as 1⅛, 1½, 2¼, 3¼. Scheerer does not entirely adopt this opinion, although he considers it worthy of notice. The smaller the angle of the boshes, the quicker is the section of the smelting fire enlarged, and the resistance decreased. Now, if Weniger, according to the generally accepted, but, nevertheless, erroneous assumption, that equal manometer pressure at equal section of tuyeres gives equal amounts of air, has used the same pressure and tuyeres with these different angles, he has of course injected more and more air in the unit of time with the decreasing angle. But the consumption in the unit of time must have increased thereby, and consequently, also, the quantity of charges, which must have produced a saving of fuel, since, at a slow descent, the transmitted heat is more unfavourable in proportion to the produced crude iron. For the heat transmitted through the walls of a furnace we refer to the notable researches by Ebelmen. *A priori*, all calculation of transmission is impossible, on account of the influence of the current of air caused by the absorption of heat by the same. Hence the laws of transmission are and remain the same as Dulong recognised them, which is, that the transmission becomes larger in proportion to the square root of the heat of the exterior walls. Our ordinary furnaces for the production of crude iron, however, require a certain loss of heat by transmission, since, otherwise, the inner walls would suffer considerably by temperatures of 2700° to 3000° C. It is otherwise with the higher portions of the furnace, where a keeping together of the heat would but be favourable to the reduction process. Practically, now, the very opposite is done. We make the outer walls as thick as possible, the inner ones as thin as possible, and expose them to all wind and weather. At equal temperatures of the walls of the furnace the expansion of the surface must be of great influence. For instance, if the temperature of the surface in the upper part of the furnace is 10° higher than the air; the transmission, according to Dulong, per hour and square metre, would be about 57 thermal units, the real, perhaps, 570 thermal units; so that in a furnace which offers 1 square metre of wall per ton of burden, there would be but half as much heat transmitted as in one which had the same quantity per 2 square metres of transmission surface. Hence Messrs. Gruner and Lan, in their "Etat présent de la Métallurgie du fer en Anglèterre" (Paris, 1862, Demot), are quite right in ascribing the saving of fuel which has been experienced of late to the enlargement in the construction of furnaces. They are not wrong, also, in ascribing the deterioration of quality in the products to this same change in the construction, and in crediting the ironmasters in Staffordshire with the determined will not to injure the renown of their productions by adhering to the traditional form rather than charging them with timidity. The saving is effected by the diminished transmission of large furnaces, which permits the consumption of less carbon for the gain of the same temperature. This small amount of carbon, however, must correspond to a less amount of carbonic oxide, and hence bring about an incomplete reduction of the ores, thus inducing a direct reduction by means of solid carbon, which, again, is the cause of an increased admixture of silicium in the products. The practical lesson from these considerations is, that all means for increase of temperature in the hearth are to be avoided, while by diminution of transmission, by quantity of heat, and by richness in reducing gases, the higher parts of the furnace are kept at the highest possible temperature, so as to obtain the maximum of production without injury to the products themselves (?). Peclet has recently shown that the capability of conducting heat is somewhat proportional to the specific gravity of different bodies; that, consequently, the porousness of a body decreases considerably its conducting capacity. The best means of limiting the transmission of a furnace is to bring about the largest possible proportion between contents and wall surface. For instance, a furnace of 1 square metre base and 3 metres height would have a contents of 3 cube metres and a perpendicular surface of 12 square metres, so that the proportion would be as 3 : 12 or 1 : 4. Another quadratic furnace of 2 metres width and 3 metres height would have 12 cube metres contents and 24 square metres wall; hence the proportion of 12 : 24 or 1 : 2. In the latter instance, with equal temperature and otherwise equal circumstances, there would be but half as much heat transmitted as in the first, and in this instance half of the fuel which is used for transmission in the first might be saved. Scheerer, in his "Lehrbuch der Metallurgie," vol. ii.,

p. 130, speaks of two coke furnaces at Neunkirch, whose dimensions he gives exactly, and which we will explain by

FIG. 116.

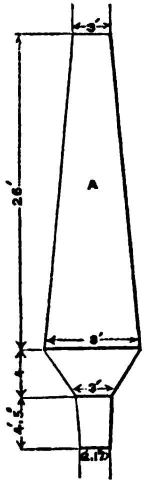
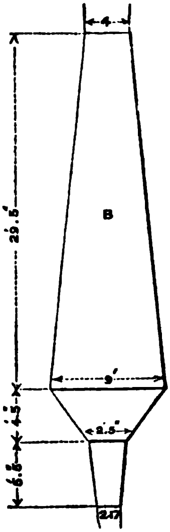


FIG. 117.



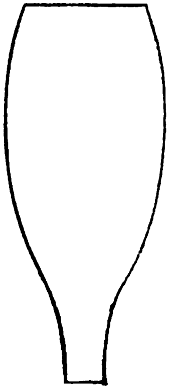
the annexed figure. The furnaces A (Fig. 116) contains 733·5 cubic feet, while its wall surface is 554·85 square feet.

The furnace B (Fig. 117) has 1117·03 cubic feet contents, and 723·20 square feet of wall surface. Whence the proportions for A are as 1 : 0·75, and for B as 1 : 0·64. The cause of the less consumption in B is, consequently, not the construction of these furnaces, but their difference in size, and the proportions thence resulting. The least transmission takes place where bad conductors are chosen for material and the wall made thick. Without any very great expense, the conducting capacity can be diminished, not only by choice of material, but also by allowing spaces, and by the construction of a last layer near the exterior wall, whose capacity for radiation is less than that of the material. Bricks from one and the same oven, if used as a coating where hot gases are active, are so different in their conducting capacities that one occasionally meets with specimens too hot for the touch of the hand, while others closely around them are almost cold.

In the choice of material, therefore, care has to be taken in separating the porous from the dense material. The former would be utterly useless for an inner coating, but will do well more towards the exterior walls. The specific gravity of bricks is easily reducible by mixing the clay with pulverised charcoal. Bricks of this kind may be made to swim upon water. The transmission can be still more diminished by leaving spaces in between the brickwork; the air enclosed in these spaces is a sufficiently bad conductor.

It is a known fact that the quantity of heat which a certain weight of cast-iron requires to melt it, 1100° to 1250°, is considerably less than the amount of heat produced in the furnace for the production of a certain amount of crude iron. This larger quantity of heat is, at least, partially demanded by the scoriæ accompanying the crude iron, which, however, is never the same with the different qualities of ore. According to the amount of slag mixed with the crude iron, more heat will be requisite and more coals spent. The addition of slags is, however, not optional; it depends upon the time which the ore needs to pass from the crater to the zone where crude iron and scoriæ begin to be smelted. This time, however, is dependent upon the reducibility of the ores; the more slags are mixed with the oxide in the ore, the longer will this oxide be exposed to the rising and reducing current of gases. As long as a complete reduction takes place before the burdens come into a region where the temperature exceeds 800°, any form of blast furnace might produce a good iron. The desire for production *en masse* in France, Belgium, and England has, for some dozens of years, made the manufacturers swerve from the traditional forms, while they, more or less, have employed the principle indicated by Fig. 118. In the Russian department of the International Exhibition of 1862 were models of long rectangular furnaces with a row of several tuyeres on each side. Furnaces of this kind were reported to have been erected for smelting copper ores in Perm, and to have been in operation during about a year and a half with success. They are known as the Rachette furnaces, and are those used in the process proposed by M. Schinz. He endeavours to show, by means of numerous experiments and calculations, that the consumption of fuel for the production of the blast is by far greater in the round furnace than in the one he employs.

FIG. 118.



A comparison based upon the mode of production as carried on in Seraing, where Ebelmen analysed the gases, resulted in showing a proportion of 5 : 33 in favour of Rachette's furnaces regarding the expense of steam for the blast. The principal feature in M. Schinz's system is, as stated above, the partial elimination of nitrogen in the products of combustion by means of carbonic oxides. Although free hydrogen would be preferable to the latter, on account of its prompter and more perfect absorption of the oxygen, yet in blast furnaces it would be entirely without effect, most probably on account of its greater diffusion. Pure carbonic oxide gas is also preferable to the carbonic oxide obtained by the combustion of carbon in atmospheric air, on account of its freedom from the obnoxious admixture of liberated nitrogen. Among the processes proposed by the inventor for the production of carbonic oxide is that described in Figs. 119 and 120. The constructions are similar to the Silesian zinc furnaces. The burning gases stream up in A, pass between the muffles into the channels, B, from whence they are exhaled through four chimneys, C, C.

FIG. 119.

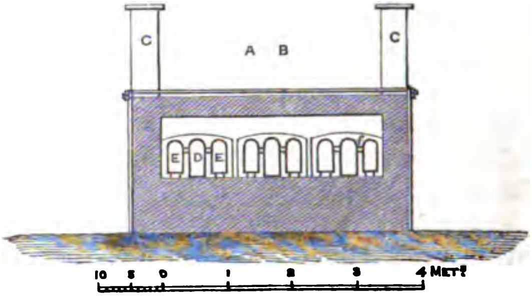
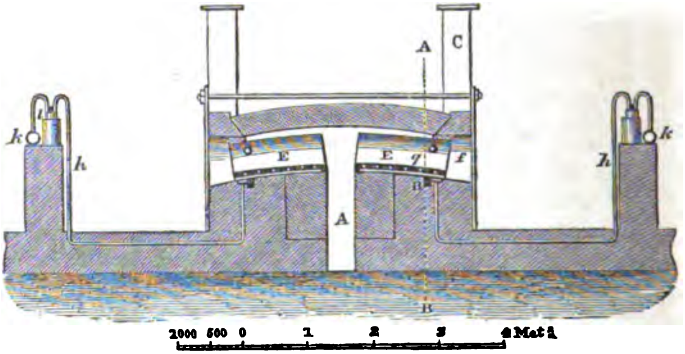
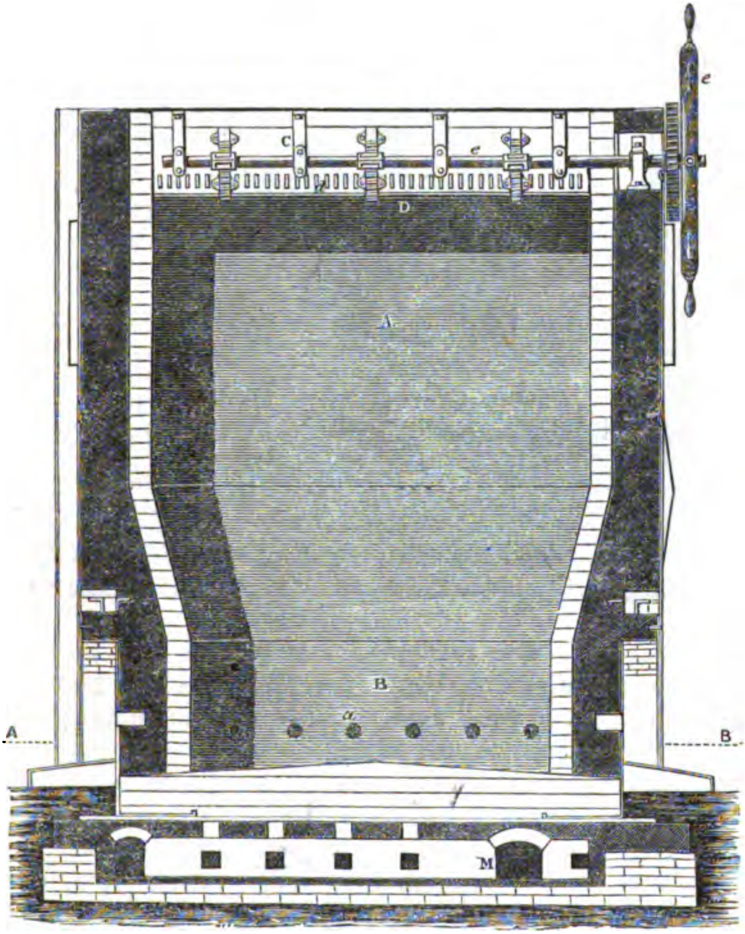


FIG. 120.



The muffles, D, are those in which the carbonate of lime is separated, and the muffles, E, E, are filled with fragments of coal. These latter are joined with D by means of short tubes, *f*, *f*, through which the carbonic acid passes into the muffles, E, E, which, near the bottom, are provided with a grate for the escape of the oxide of carbon, which thence passes into the tubes, ***h***, ***h***. The muffles are easily closed by means of a thin wall of stones cemented with a mixture of clay and damp sand.

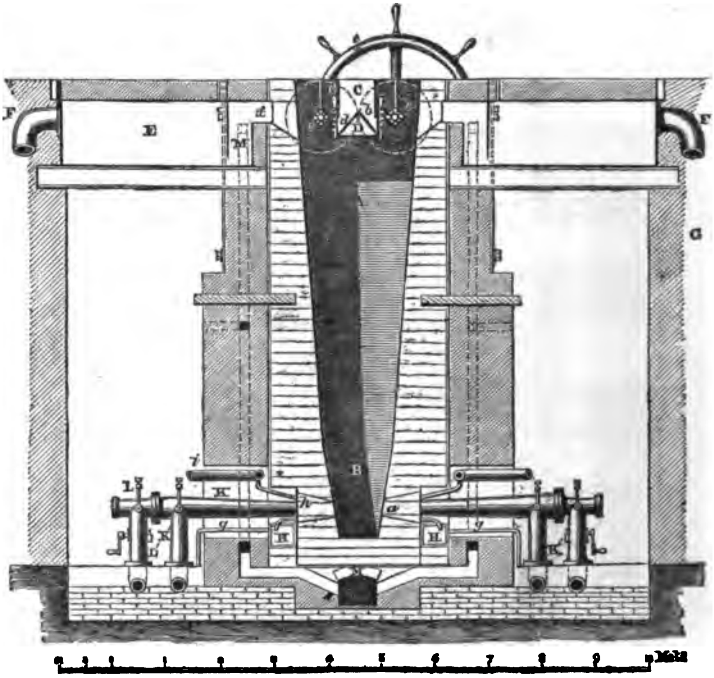
FIG. 121.



The carbonic oxide is conducted through washing vessels and then gathered in a reservoir; from thence it is inhaled by blast engines and through tubes blown into a vessel standing on the side of the blast furnace, from whence it passes into the furnace.

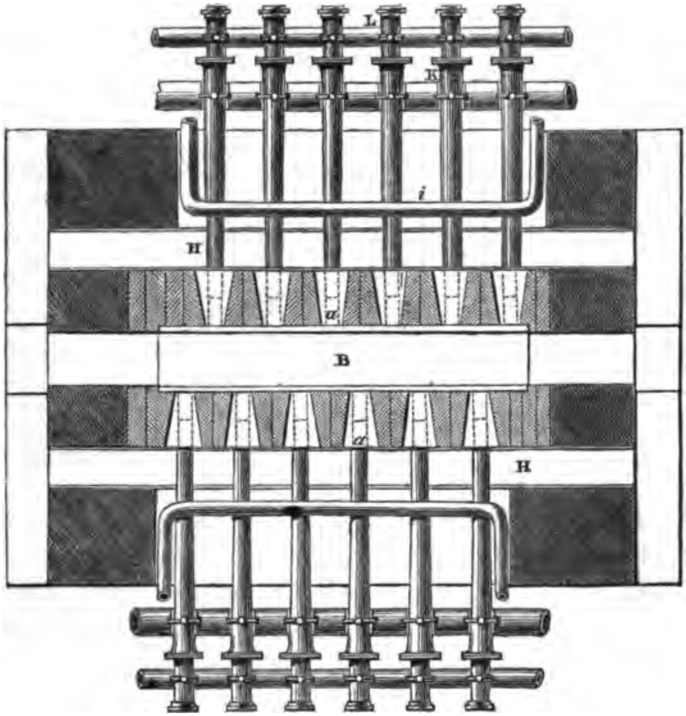
Figs. 121 and 122 show the arrangement of the furnace itself. The twelve tuyeres, *a*, *a*, *a*, are specially shown in the horizontal section, Fig. 123, according to A, B, Fig. 121. C is the pre-heating zone, capable of containing 3 cube metres, while the volume of the hourly charge is not quite 1 cube metre, so that the ores and cokes do not form a high layer in the same. The hollow triangular cast-iron beam, D, D, protrudes through the walls of the furnace, and is open at both ends, so that the air can enter through the apertures, *b*, *b*, into C. The perpendicular movable

FIG. 122.



plates, *c*, *c*, are also provided with apertures, *d*, *d*, through which the gas out of the furnace passes directly into C, where it burns with the air from D. Here *e*, *e*, *e*, represents the arrangement for lifting or lowering the plates, *c*, *c*. By its position, as indicated in the figure, the space, C, is closed; a lifting of the plates would produce a lapse of the pre-heated

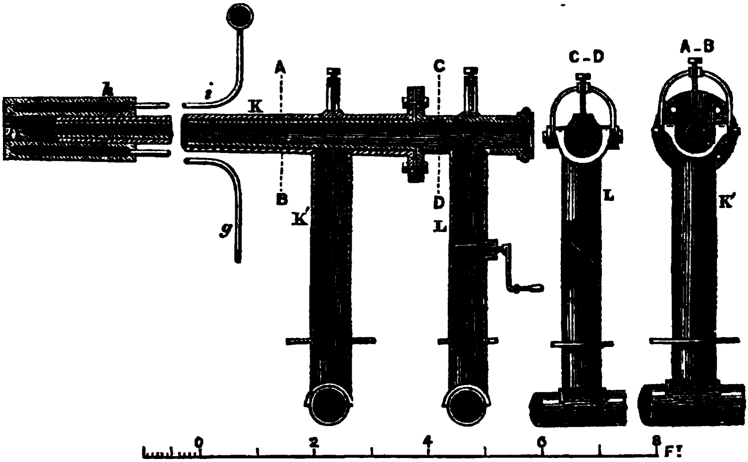
FIG. 123.



burdens into A. The apertures, *b*, *b*, and *d*, *d*, must be made only of size sufficient to pass the quantity of gas and air required. The larger quantity of the gases passes off symmetrically sideways through several channels, *f*, *f*, into the large cast-iron boxes, E, E, in which the gases are cleansed from the dust which they carry with them. The tubes, F, F, are let into the walls, G, G, in order to diminish the cooling of the gases, for the further transmission of which they serve. The tubes, *g*, *g*, supply the cast-iron beams, H, H, with cooling water, which from them passes into *h*, *h*, from whence it is carried away by the tubes, *i*, *i*.

Fig. 124 shows more minutely the construction of the air tuyeres, K, and the gas tuyeres, L. Both are hermetically fastened on the perpendicular feeding-pipes, K′, L′, and the gas tuyere, L, is concentrically united with the air-tuyere, K. The channels, M, M, are the chambers for the ignition of the fuel, and are a distinguishing mark of Rachette's system.

FIG. 124.



The above extracts will give our readers some idea of the extent to which M. Schinz has carried his laborious researches. It is to be hoped that ere long we shall hear of practical experiments resulting from the application of his patent.

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## THE RICHARDSON PUDDLING PROCESS.[*]

The first great fact is, that the necessity for refined or "plate" metal—and therefore the refinery—is dispensed with, the best results having been obtained from charges consisting of pig-iron alone. The common pig is piled on the puddling hearth in the ordinary manner, and as soon as it has melted, a blast of atmospheric air of a pressure of 5 or

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[*] The Practical Mechanic's Journal, August, 1867.

6 lbs. on the square inch is introduced into its mass by means of a tubular rabble, the blast being led thereto through a flexible pipe coupled to the outer end of the hollow rabble handle. The action of the blast prevents the molten iron from closing the holes in the rabble, and, in operating with it, the puddler pushes it about in the molten mass over every part of the furnace with as much ease as with a common rabble, thus causing a very rapid conversion and elimination of all the impurities that oxygen is capable of separating.

It is not at all propable that any phosphorus is eliminated during this period of blowing in. By the means we have mentioned the iron is brought to nature in a very short time, the rabble being kept in until the mass boils up level with the stopper hole, or, if desired, the blast may be kept in until the iron assumes the pasty condition, a period ranging from about six to nine minutes. As soon as the blast is withdrawn, the charge is stirred about in the ordinary way by a common rabble until the iron has separated from the cinder in lumps, after which it is collected and balled up in the ordinary manner, the balls being allowed to remain in a sufficient time to permit the *probable liquation or sweating out of the phosphides of iron*, after which the iron is shingled and rolled into bars, plates, or uses in the ordinary manner.

## ON CERTAIN POINTS IN THE MANUFACTURE OF MALLEABLE IRON, WITH SPECIAL REFERENCE TO THE RICHARDSON PROCESS.*

By St. John Vincent Day, C.E., F.R.S.S.A., &c.

Since the year 1784, when Cort introduced the process of puddling, there has not been any really great advance made in improving the general results obtainable from the conversion of crude or pig into malleable iron in the puddling furnace until very recently.

By no means do I here intend to arrogate for Cort the raising of the puddling process to its present state of comparative efficiency, for no matter how very imperfect that process yet remains, still it is well known that the results produced by it were not generally to be depended upon until long after the inventor's unfortunate career terminated with his death—indeed, the first quarter of the present century had nearly passed away ere the puddler's manipulations could be relied upon continuously; and it is highly probable that even then the uncertainties of production would not have been largely removed but for the careful attention of some of the English iron-masters, who perceived a wide field opening up for a high class of manufactured material in the iron canal and river boats and railways, then coming into vogue, and, later still, in supplying that required for our great tubular and girder bridges and lines of trans-oceanic steamships.

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* Read before the Institution of Engineers in Scotland, January 15, 1868.

During the present century, however, innumerable attempts at improving the process have been made at home, on the Continent, and in America, still with no good effect generally; indeed, the value of what has been done, taken on a broad, practical, and, therefore, commercial basis, has been extremely small. It is, however, perfectly true that the failures which have been encountered have increased our stock of information as to the peculiarities, or rather specialities, of the compound we have been treating in the puddling furnace, and in this particular view recorded failures, when accompanied by a faithful declaration of what took place, are of the highest importance. As a very striking instance, I may allude to the most recent and gigantic failure that has and probably ever will occur in a future time in the metallurgy of iron—I allude to the impossibility of making good commercial iron out of the ordinary ores of this country by the Bessemer process. Mr. Bessemer has himself on several occasions openly confessed that he could not succeed in making good malleable iron by his process, purely on account of the impossibility of removing sulphur, but more particularly phosphorus, in the converter. His early experiments showed distinctly that, whilst the highly oxidising effect of the blast injected into the converter was most efficient in removing carbon and silicon and some of the lesser impurities, still the phosphorus and sulphur remained untouched;

the immediate consequence of which has been that his process has never come into practice *for making iron from the ordinary run of British ores*, by far the larger portion of which contain notable quantities of these two elements, of which phosphorus is the greater enemy, its presence rendering the iron *cold-short*, whilst sulphur has the opposite effect of rendering it *red-short.*

I have before referred to Cort's process, and prior to directing attention to the more immediate subject of this paper, it will be an advantage, in a casual way, to refresh our memories by considering what has been done successfully towards the improvement of puddling since his day up to the present time. Before doing so, however, I wish to remark that, although the invention of puddling is usually ascribed to Cort, there exist very grave reasons for withdrawing from him the origination of it, as a reference to the specification of a patent granted to Thomas and George Cranage in 1766 will easily show.

The Messrs. Cranage were workmen employed at Colebrookdale, and it is recorded that puddling was practised there prior to Cort's invention, for when the latter applied to Mr. Reynolds, at that time the manager of the works, he replied in his Quaker tongue, "If thou wilt come with me to the works, I will soon show thee the thing done." Cort went, and at the command of Reynolds, Tom Cranage made a puddled ball in their presence. It appears, however, that the process was not carried out on a large scale at Colebrookdale until after Cort had been there, so that it is probable some practical difficulty existed in what the Brothers Cranage had done. This fact would show that to Cort must unquestionably be attributed the high distinction of being the perfecter rather than the inventor of the process called "puddling."

The process of puddling, too, was very completely set forth in the specification of Peter Onions in May, 1783, about a year prior to the date of Cort's patent; indeed, it appears extremely probable that iron-masters at that period, hearing of the partial success of the Cranage process, had begun to set themselves the task of perfecting it: hence the inventions of Onions and Cort so close one upon the other.

The question of Cort's invention has, however, been so frequently discussed elsewhere that I need not further allude to it here; the deplorable tale connected with it is so well known to us all that it need not be again enlarged upon.

The next great step of improvement that presented itself was that of Mr. Samuel Baldwyn Rogers, of Nant-y-Glo, who substituted the "iron bottom" for Cort's sand bottom. This,.like every other really valuable discovery, was condemned by the Welsh iron-masters, and after it had been derided at by Mr. Hall, of the Rhymney Iron Works, Mr. Hill, of the Plymouth Iron Works, Mr. Homfray, of Tredegar, Mr. Crawshay, of Cyfartha, Mr. Forman, of Pendarren, and others, it was ultimately tried at Ebbw Vale by Mr. Richard Harford, who, on discovering the advantages about or shortly after the year 1818, adopted it, since which time others followed his course until wherever puddling is now practised the cast-iron bottoms are used.

Rogers's fate as an inventor was as sad as his unfortunate predecessor, Cort; both lived for years, and ultimately died in absolute penury.

The "boiling process" was the next great stride: it is generally attributed to Mr. Joseph Hall, of the Bloomfield Iron Works.

"Boiling" is produced by charging certain oxidised compounds of iron on the puddling hearth, from which, as soon as melted, some of the oxygen begins to separate, and, uniting with some of the carbon of the iron, forms carbonic oxide, the presence of which may always be detected by the well-known bubbling about of the metal, attended with endless escaping jets of blue flame. Until the charge is melted the solid oxide is covered with liquid cinder, composed in great part of protoxide of iron; this being combined with silica, constitutes a silicate of protoxide of iron, which, after melting, combines with additional silicon in the pig and some of the iron of the charge, forming the tribasic silicate of protoxide of iron ($3FeO,SiO_3$), without the presence of which the process of puddling could not be carried on, this silicate possessing the peculiar property of not further oxidising iron at the most exalted temperatures employed, and being easily separated from it, so that, although the granules of iron in the puddling furnace after the boiling stage is over, and the temperature of the furnace is lowered, are lying scattered about in it, still, on being pressed together, they unite, the fluid silicate being easily squeezed out from between the surfaces of contact by means of the puddlers' balling rod, whilst that portion which still clings to the iron after the balling is over is what we see extracted from the mass under the shingling hammer and between the roughing rolls. Boiling, then, along with the use of roasted tap cinder, or "bull-dog," as it is generally termed, constitutes the last great step in the chemistry of the process since the time of Cort.

In the mechanical operations of puddling, and in the construction of the furnace, several attempts towards improvement have been and continue to be made. In the furnace itself the use of water-troughs through the bridge, and in some cases forming the sides of the puddling hearth, have come into practice, but their value in a sense of effecting ultimate economy, for several reasons, appears to me to be very questionable. Double furnaces, too, have been tried—that is to say, furnaces capable of containing a double charge of metal, and with a puddler working at both sides; but it is a striking fact that they are being given up, and the old-fashioned single furnace still obtains. I am informed by some of the Scotch iron-masters that the iron from the double furnace is never so good as from the single furnace, and the charge is generally longer in melting. The chief object intended by their introduction was a diminution in the fuel consumed per weight of iron manufactured; this, to some extent, is obtained, and probably herein consists the reason why the charge is longer in melting. Considerably less than twice the weight of fuel has to melt exactly twice the weight of iron; but the furnace is not twice as large, generally not more than 10 or 11 inches, or less than a foot, broader than a single furnace, the height and length being the same, so that the space occupied by the heat from the fuel in the double is nearly proportional to that of a single furnace; but as the charge of iron therein is proportionately very much greater than the fuel, it follows that a longer time of melting should obtain; at least, the question having been submitted to me for consideration, this is the only reasonable view I have been able to arrive at. As to the quality of the iron produced in double puddling furnaces being frequently inferior and of indifferent nature, I cannot account for that in any other way than by looking at the cause as inherent in the difficulty of getting the two puddlers to work the two portions of the charge in concert with each other; it is almost certain that one will work his part of the charge more or less than the other, thus producing iron in the same furnace necessarily of dissimilar quality. However, the cause of inferiority of double puddling furnaces against single is a question by no means thoroughly investigated, and it forms a topic which I think this Institution might discuss with obviously great advantage. It is probable that when a perfect system of mechanical puddling is devised, that then, provided such is effected by the movement of rabbles, double furnaces may be generally adopted, as certainty of similar action of the two instruments may then be insured by their being placed under the control of properly arranged machinery.

Speaking of mechanical puddling, numerous expedients have been tried, but with no practical success generally, in Great Britain. At Dowlais almost every hitherto conceivable means for doing away with the puddler has been resorted to, but with what result? I have no doubt that many of the members of this Institution will remember the singular paper read by Mr. Menelaus to the Institution of Mechanical Engineers, who met at Paris during the past summer—a paper, I say, singular, because it was so very dissimilar to what papers read before such institutions usually are; we generally and naturally find ourselves and others recounting our and their successes, but here Mr. Menelaus in the most laudable manner has placed on record everything that has been done at those gigantic works under his control, all of which has ended in failure, and he has not attempted to hide the failures either.

At Dowlais, too, Mr. Anthony Bessemer's revolving puddling furnace has been used, but it has failed; as well, I believe, the injection of steam by a tube or blast-pipe, according to Mr. Nasmyth's plan; also air and steam combined after the process of Guenyveau; and, I am told, even the introduction of a blast of air alone through a blast-pipe—still all ended in absolute failure.

The most successful experiments in connection with mechanical puddling that have come under my notice were those conducted by MM. Dumeny and Lemut at the Clos-Mortier Forge, in the commune of St. Dizier (Haut Marne). I will not now take up your time in describing the various mechanical arrangements they have adopted, but merely state that I some time since received a report in which they assert the practical results of their apparatus are—1st, That the consumption of fuel is greatly reduced per ton of metal produced; 2nd, The work is accelerated and the production of the furnace increased, from which economy in the general and working expenses has resulted; 3rd, The obviating the necessity of workmen in stirring the cast-iron lowers the price of labour, whilst, at the same time, it enables the wages of the regular puddler to be augmented, although the labour is lightened; 4th, The waste is about the same as in the system of ordinary puddling, which is equivalent to saying (in other words) that the yield is the same as under the hand system; 5th, The improvement in the quality of the iron is undoubtedly the effect of the mechanical puddler.

Having now drawn a sketch of puddling from its earliest date down to the present time, I proceed to direct your attention to some remarkable facts connected with a new process, viz., "The Richardson Process," which I am sure will be of great interest, as it is of the gravest importance to nearly every member of this Institution, being particularly interesting because the chief practice with it has taken place in the neighbourhood of Glasgow. Of this process and its results some facts have lately appeared in the engineering journals, and I am happy to be able to state that, in the views which I originally formed, my conclusions have since been fully borne out by the remarkably accordant results we have obtained at the Glasgow Iron Works, but more particularly at Parkhead Forge.

Generally, I have no doubt the members of this Institution are aware in what the "Richardson Process" consists. I will presently, in few words, explain its chief feature, but first wish to mention what has been previously attempted in a similar direction. Reuben Plant was among the first to introduce blasts of air and steam into the puddling furnace, and provided he had continued his experiments to completeness, there is little doubt but that what is now known as the "Richardson Process" would have been an established mode of manufacture twenty years ago. As it is, to Mr. Richardson, who was associated with Plant at that time, the credit is due of having made the first recorded experiments of blowing air below the surface of fluid pig-iron, when he obtained that peculiar series of changes which we daily see produced in the Bessemer converter. Had Mr. Richardson continued the blowing of air long enough, there is no doubt he would have succeeded in making worthless malleable iron, as Mr. Bessemer has done, though not being able to eliminate the sulphur and phosphorus. Other circumstances, as Mr. Richardson informs me, interfered, that a stop was put to the prosecution of the experiments, and thus it became reserved for Mr. Bessemer to follow up that same line of triumphant investigation by which he has immortalised his name—the process for making "Bessemer steel."

At Dowlais, in particular, as well as at Cwm-Avon Iron Works, in Glamorganshire, blasts of air were blown into the metal on the puddling hearth, but for a very different object to that which the "Richardson Process" seeks to effect. In all the experiments, as I am informed, that were made prior to Richardson's, the blowing was continued for a long time after the iron had been brought to the boil. Now it is perfectly clear that in an ordinary furnace such continuous pouring in of oxygen would boil the metal to such an extent that it must run rapidly away with the slag from the stopper-hole, and being continued long after the desilicatisation and decarburisation of the charge were effected, would oxidise the iron to an enormous extent, thus diminishing the yield so much as to reduce the iron-masters' profits to a degree that could not be tolerated. But these are not all the defects of such a constant in-pouring of oxygen; the powerful attack upon the carbon and the silicon, and after that the combination with the iron itself, must raise the temperature of the furnace to such an extent that the bricks usually employed in the construction of such furnaces would melt away, and the life or duration of the furnace would therefore be reduced to a comparatively brief existence; and I may here remark what is a singular fact, that although persons originally engaged in such experiments did not discover a remedy for this evil, it is well known that for puddling furnaces common soft bricks are employed, the higher limit of temperature employed for puddling not requiring the use of the harder and more durable kinds which are used for furnaces wherein the temperature ranges higher. The same defect of the more rapid destruction of the roof has been met with in recent processes for making steel, but that has been entirely overcome by the use of harder bricks and a higher roof. Having now shown the general nature of previous attempts, I proceed to explain the different course of action that Mr. Richardson adopts. In place of continuous blowing, the blast is introduced through a tubular rabble connected with a blast receiver immediately after the charge is melted, and continued until the metal is brought to "the boil," when it is withdrawn. The period from the melting to the boil with the iron used at Parkhead under the common method of puddling occupies from twenty-five to forty minutes; this, by the Richardson process, is reduced to ten minutes. The temperature of the furnace being higher, the period from the commencement of the boil to that when decarburisation and desilicatisation are completed, and the iron separates from the slag and cinder, is again reduced. But the balling operation is of a little longer duration than under the old method, on account also of the greater temperature, the granules of iron requiring more time to cool down to that temperature at which they adhere when pressed together. The following table No. 1, of some of the first experiments made at the Glasgow Iron Works, shows the time occupied in conducting each stage of the process, as well as the yield:—

### TABLE I.—EXPERIMENTS AT THE GLASGOW IRON COMPANY'S WORKS.

| Date of Experiment, and No. of Furnace. | Weight of Charge. | | Charge composed of. | Time of Charging. | | Iron Melted at | | Blast put in at | | Blast on till | | First Ball out. | | Last Ball out. | | Time occupied from Charging until the Iron was finished. | | Yield. | | | Diminution of Charge. | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cwts. | lbs. | | H. | M. | H. | M. | H. | M. | H. | M. | H. | M. | H. | M. | H. | M. | cwts. | qrs. | lbs. | cwts. | qrs. | lbs. | |
| 30th May, 1867. Furnace No. 17 | 4 | 0 | Pig-iron exclusively. | 7 | 0 | 7 | 27 | 7 | 28 | 7 | 36 | 8 | 4 | 8 | 8 | 1 | 8 | Not ascertained. | | | Not ascertained. | | | |
| 11th June. Furnace No. 17 | 4 | 0 | Pig-iron exclusively. | 6 | 12 | 6 | 42 | 6 | 43 | 6 | 47 | 7 | 18 | 7 | 22 | 1 | 10 | 3 | 3 | 14 | 0 | 0 | 14 | Three rabbles used to prevent any one becoming too hot. |
| 11th June. Furnace No. 17, re-fettled . . | 4 | 0 | Three cwts. pig-iron and 1 cwt. refined or plate metal. | 7 | 30 | 8 | 1 | 8 | 1·5 | 8 | 6·5 | 8 | 35 | 8 | 40 | 1 | 10 | 3 | 2 | 14 | 0 | 1 | 14 | Same number of rabbles used as in the preceding experiment. |
| 13th June. Furnace No. 17 . | 4 | 0 | Common pig of the worst quality used in the works for a long time. | 6 | 5 | 6 | 35 | 6 | 35 | 6 | 43 | 7 | 16 | 7 | 20 | 1 | 15 | 3 | 2 | 7 | 0 | 1 | 21 | Three rabbles used. |
| 13th June. Furnace No. 17 . Furnace re-fettled and again charged | 4 | 0 | Same as in the preceding experiment. | 7 | 30 | 8 | 3 | 8 | 4 | 8 | 12 | 8 | 36 | 8 | 41 | 1 | 15 | 3 | 3 | 18 | 0 | 0 | 10 | Five rabbles used. |
| Means . . . | 4 | 0 | | Mean time of blowing in, 6·36 minutes. | | | | | | | | | | | | 1 | 11 | 3 | 2 | 27·25 | 0 | 1 | 0·75 | The rabbles are very little affected, and therefore will last a long time. |

In these experiments the time of working a charge composed entirely of Scotch pig was brought down to one hour and eight minutes, whereas the usual time is from one hour thirty minutes to one hour forty-five minutes under the old method; the yield is considerably higher; so high, indeed, as to require only 21 cwts. 1 qr. 17 lbs. of pig-iron to produce a ton of malleable iron, showing a loss on the conversion of only about 6 per cent. Then as to the purity of the iron, it is most remarkable; two samples which I sent to Dr. Stevenson Macadam, of Edinburgh, to be analysed have given the following results:—

*Analysis.*

| Name of Element. | Square Bar. | Round Bar. |
|---|---|---|
| Iron . . . . . . | 99·569 | 99·648 |
| Carbon . . . . . | 0·035 | 0·031 |
| Silicon . . . . . | 0·076 | 0·075 |
| Sulphur . . . . | 0·025 | 0·028 |
| Phosphorus . . . | 0·031 | 0·034 |
| Manganese . . . | trace | trace |
| | 99·736 | 99·816 |

We see the sulphur and phosphorus are within the merest shadow of being entirely eliminated, evidently showing that some special influence must be present when puddling iron according to Richardson's system that is not found elsewhere; iron never has been made from British ores, on a commercial scale, so pure as in these two instances. Made from inferior Scotch pig, which always contains such a very large percentage of these two elements, the extent of their elimination is all the more remarkable. But not to draw any hasty conclusions, I have prepared tables Nos. 2, 3, 4, 5, 6, 7, and 8, showing the percentages of these two elements in all the British pig-irons, from the analyses published in the Blue Book "On Cast-iron Experiments."

The only analysis of pig-iron from North Staffordshire that I possess contains the very high proportion of 1·07 of phosphorus, and 0·04 of sulphur.

It is a very remarkable fact that I have not been able to obtain many reliable analyses of blackband pig-iron, or, indeed, of the other Scottish irons, that are guaranteed by

Table II.—Hæmatites. Sulphur and Phosphorus Combined in Pig-Iron made in Whitehaven and Ulverstone Districts from Hæmatite Ores.

| Particulars as to the Ores from which the Pig-iron was made. | Means of Sulphur. | Means of Phosphorus. | Remarks. |
|---|---|---|---|
| Red Hæmatite from Whitehaven, Cumberland, and Cleator Moor. | 0·053 | 0·0475 | Whitehaven Foundry Pig, Nos. 1, 2, 3, 4, hot blast. |
| Ulverstone Ore. | 0·030 | 0·1000 | Pig-iron made at the Newland Furnaces, Ulverstone. |
| Ores in the locality of Durham. | 0·090 | 0·1410 | Iron smelted by the Weardale Iron and by the Forest of Dean Co., at Parkhead Iron Works. |
| Ulverstone Hæmatite (anhydrous sesquioxide), 25 parts; Forest of Dean hæmatite (hydrated sesquioxide), 5 parts; brown hæmatite, believed to be from Froghall, 25 parts; Gubbin ironstone, 10 parts (roasted); bottom whitestone, 5 parts (roasted). | 0·050 | 0·2900 | Pig-iron made by Messrs. Firmstone and Co., Lays Iron Works. |
| Mean of means. .. .. | 0·056 | 0·1446 | |

Table III.—Chiefly Argillaceous Ores from the Coal Measures. Sulphur and Phosphorus Combined in Pig-Iron made in South Wales.

| Particulars of the Ores from which the Pig-iron was made. | Means of Sulphur. | Means of Phosphorus. | Remarks. |
|---|---|---|---|
| Wholly of Welsh mine, without cinder or red ore. | 0·235 | 0·032 | Pig iron made at Dowlais, of which the first three samples were of No. 3 best mine pig, cold blast; mottled mine pig, cold blast, and white mine pig, cold blast, respectively; while the fourth was best mine pig, melted in a furnace with three tuyeres, of which two were hot and one cold blast. |
| Black pins, Pwll Llacca Bottom vein, Ball mine, and Grey vein. | 0·074 | 0·32 | Made at Blanaevon with cold blast. |
| From the coal measures of the locality, the precise names of ore unknown. | 0·059 | 0·31 | Made at Blanaevon, and specified as cold-blast grey pig-iron; analysed at the Arsenal, Woolwich. |
| Red or Welsh mine and cinder. | 0·75 | 0·79 | The first of these samples cast in chills, the second in sand, to ascertain the difference chemically by the two modes of being cooled. It is surprising that, whilst so small a proportionate difference shows itself in the carbon, the proportionate difference in the phosphorus is very great. |

TABLE III. (continued).

| Particulars of the Ores from which the Pig-Iron was made. | Means of Sulphur. | Means of Phosphorus. | Remarks. |
|---|---|---|---|
| From the coal measures in the locality of Pontypool. | 0·096 | 0·426 | Cold blast grey pig made at Pontypool. |
| Caus-y-Glo or Cheese mine, Pimmelyn mine, or yellow pin with red hæmatite from Ulverstone. | 0·060 | 0·360 | Made at Ystalyfera, near Swansea; hot blast. |
| Mean of means . . | 0·098 | 0·473 | |

### TABLE IV.—ARGILLACEOUS ORES FROM THE COAL MEASURES. SULPHUR AND PHOSPHORUS COMBINED IN PIG-IRON MADE IN SOUTH STAFFORDSHIRE.

| Particulars as to the Ores from which the Pig-iron was made. | Means of Sulphur. | Means of Phosphorus. | Remarks. |
|---|---|---|---|
| Binds, whitestone, gubbin, and grains, proportions unknown. | 0·0440 | 0·362 | |
| Ibid. | 0·0675 | 0·400 | Cold blast grey pig-iron. |
| Bottomstone and binds; two-thirds gubbin, and rubble one-third. | 0·6300 | 0·530 | Pig, grey—forge, and forge pig respectively; cold blast iron made at the Parkhead Furnaces, Dudley. |
| Ibid. | 0·0630 | 0·530 | Cold blast grey pig made at the Parkhead Furnaces, Dudley. |
| Gubbin one-half, whitestone the other half. | 0·0450 | 0·670 | Hot blast and cold blast respectively, from Earl Dudley's Level Iron Works, Brierley Hill. |
| Whitestone, gubbin, grains, pins, balls, and poor robins, with a little red hæmatite from Ulverstone. | 0·0625 | 0·490 | Pig-iron made by Messrs. Badger and Co., Old Hill Furnaces, Dudley; whether by hot or cold blast is unknown. |
| Uncertain as to name. | 0·0800 | 0·390 | Grey pig, both hot and cold blast, from Lays Iron Works, Dudley. |
| Mean of means. . . . | 0·0614 | 0·480 | |

### TABLE V.—ARGILLACEOUS ORES FROM THE COAL MEASURES. SULPHUR AND PHOSPHORUS COMBINED IN PIG-IRON MADE IN YORKSHIRE.

| Particulars as to the Ores from which the Pig-iron is made. | Means of Sulphur. | Means of Phosphorus. | Remarks. |
|---|---|---|---|
| Black bed ironstone from the coal measures of this locality. | 0·050 | 0·540 | Various kinds, specified as pig and grey pig made at the Bowling Iron Works. |
| Ibid. | 0·054 | 0·558 | Cold blast pig-iron made at Messrs. Harding and Co., Beeston Manor Iron Works, Leeds. |
| Mean of means . . . | 0·052 | 0·549 | |

### TABLE VI.—ARGILLACEOUS ORES FROM THE COAL MEASURES. SULPHUR AND PHOSPHORUS COMBINED IN PIG-IRON MADE IN DERBYSHIRE.

| Particulars as to the Ores from which the Pig-Iron was made. | Means of Sulphur. | Means of Phosphorus. | Remarks. |
|---|---|---|---|
| The first three samples in this case made of Brown Rake ironstone, and the fourth from Blue Rake ironstone (ore roasted). | 0·0475 | 1·050 | Pig Nos. 1, 2, 3, 4, made by Messrs. Needham, Butterley Iron Works, near Alfreton, Derbyshire; hot blast. |
| Black and Gray Rake two-thirds, and Honeycroft or Striped Rake, one-third. | 0·0420 | 0·680 | Various, foundry pig and grey forge pig, made at the West Hallam Iron Works. |
| Mean of means .. .. | 0·0447 | 0·865 | |

### TABLE VII.—SULPHUR AND PHOSPHORUS COMBINED IN PIG-IRON MADE ENTIRELY OF NORTHAMPTONSHIRE ORES.

| Particulars as to the Ores from which the Pig-Iron was made. | Means of Sulphur. | Means of Phosphorus. | Remarks. |
|---|---|---|---|
| The usual ores of this neighbourhood. | 0·438 | 1·1270 | |
| Ibid. | 0·100 | 1·1600 | Made by Messrs. Battlin and Co. with cold blast. |
| Mean of means .. .. | 0·269 | 1·1435 | |

### TABLE VIII.—SULPHUR AND PHOSPHORUS COMBINED IN PIG-IRON MADE FROM CLEVELAND ORES.

| Particulars as to the Ores from which the Pig-Iron was made. | Means of Sulphur. | Means of Phosphorus. | Remarks. |
|---|---|---|---|
| Uncertain. | 0·035 | 1·27 | Iron known as No. 2 foundry pig, made at South Bank Furnaces, Middlesbro'-on-Tees; hot blast. |
| Cleveland ore from Belmont mines, and a little red hæmatite. | 0·035 | 1·37 | Made by Messrs. Holdsworth, Bennington, and Byers, at Stockton; hot blast. |
| Mean of means .. .. | 0·035 | 1·32 | |

authority; this is not only a peculiarly striking fact; it is, moreover, one to be greatly deplored. It is true that I am in possession of several analyses in which phosphorus does not present itself at all; this certainly is notorious, as it is well known that the blackband pig-irons do contain a very large percentage of phosphorus, and I can therefore only suppose that this element, always most difficult of detection, has not been carefully sought for. The paucity of analyses in this respect is no doubt principally due to the fact that so much of the Scotch pig-iron is used and exported from the country as "foundry iron." Now, it is perfectly evident that, for foundry purposes, the presence of phosphorus is of considerably less importance than would result if the pigs were as largely used for making malleable iron as the

English, Welsh, and Continental ores. It being certain that the presence of phosphorus has so much to do with the tensile strength of malleable iron, this, no doubt, has been the chief incentive to the undertaking so many careful analyses of those pig-irons from which malleable iron is principally made, in order that to produce the highest quality of finished iron, ores containing the least amount of phosphorus might be selected.

I may call attention to one analysis of Scotch blackband ironstone, which we may safely take as a very fair mean representative of the productions of this country. It is from Gartsherrie, and my authority for it is a report made to the Prussian Government by M. A. Erbeich. In the raw state it gives phosphoric acid ($PO_5$) 0·90, which corresponds to rather above 0·5 per cent of phosphorus in the pig-iron, but we may with safety take it at 0·5 per cent, for the sake of avoiding error in excess. Some samples of Scotch pig-iron give sulphur and phosphorus in other proportions; for instance, some No. 3 grey coke iron from the Calder Iron Works contained sulphur 0·35 and phosphorus 0·39, and another specimen from Clyde contained sulphur 0·40 and phosphorus 1·30; the former of these is probably a fair mean representative of the quantities of sulphur and phosphorus combined in irons from the Scotch coal measures, whilst the latter is no doubt an extreme; taking, however, the mean of these three, we get—

| | |
|---|---|
| Sulphur | 0·375 |
| Phosphorus | 0·630 |

From the appended tables we have the values of British pig-irons in regard to phosphorus represented in the following scale of ascending values of the quantity of that element by their mean of means:—

| | Phosphorus, per cent. |
|---|---|
| Hæmatites (various) | 0·144 |
| South Wales | 0·473 |
| Staffordshire (South) | 0·480 |
| Yorkshire | 0·540 |
| Scotland | 0·730 |
| Derbyshire | 0·865 |
| Staffordshire (North) | 1·070 |
| Northamptonshire | 1·143 |
| Cleveland | 1·320 |

On the other hand, taking the mean of means of sulphur, we get the following order of ascending values in respect of the quantity of this element contained in the ores of different localities of Great Britain :—

| | Sulphur, per cent. |
|---|---|
| Cleveland | 0·0350 |
| North Staffordshire | 0·0400 |
| Derbyshire | 0·0447 |
| Yorkshire | 0·0520 |
| Whitehaven (Ulverstone) | 0·0560 |
| South Staffordshire | 0·0614 |
| South Wales | 0·0980 |
| Northamptonshire | 0·2670 |
| Scotland | 0·2830 |

Now, since the effect of combined sulphur is to prolong the time of melting, and phosphorus, on the other hand, diminishes that period, comparisons like those we have made are extremely useful in indicating the other chemical conditions in addition to those produced by the presence of carbon and silicon, that affect the duration of the period of melting of pig-irons made in different localities. I am now, of course, speaking independently of the construction of the furnace, for this modifies the time of melting to a considerable extent, a high bridge and great depth of hearth tending to drive off and prevent the tips of the reverberated flame from attacking the charge so easily as in a furnace with a low bridge and shallow hearth. In the case of the Cleveland ore, we see at a glance that in the phosphorus series it is the very last, whilst, singularly enough, in the sulphur series it takes the first place ; this theory shows it should be a very fast-melting pig-iron. In the case of North Staffordshire it is second in the sulphur series and seventh in the phosphorus series ; the presence of sulphur being low, and that of phosphorus very high, it should be a very fast-melting iron. In the case of Derbyshire, the phosphorus is much lower than in the preceding, and the sulphur but very slightly increased ; it therefore should take a little longer in melting than the North Staffordshire pigs. In the case of Yorkshire the sulphur is increased, and the phosphorus diminished ; the time of melting should be longer still.

By making comparisons like the foregoing we obtain the period of melting of British pig-irons in terms of the combined sulphur and phosphorus in the following order:—

Cleveland,
North Staffordshire,
Derbyshire,
Yorkshire,
Northamptonshire,
Whitehaven, Ulverstone (Hæmatite).
South Staffordshire,
South Wales,
Scotland.

Here we see the order is nearly the same as in the sulphur series, the exception being in the case of Northamptonshire pig, where the percentage of phosphorus is so very high that it predominates over the sulphur, and therefore materially shortens the period of melting. If these conclusions which I have deduced are compared with practical results they will, I believe, be found to very fairly coincide. In the case of Scottish irons these should take longer to melt than any others present in this country, and from the number of trials at different works that have been made on this point, such deduction will, I believe, strictly correspond with the practical results.

We have now to consider the extent to which phosphorus and sulphur are removed in the ordinary process of puddling. On this point I have not had time to prepare tables, as in the case of pig-iron, but it is my intention to do so on the earliest opportunity, as their value is evident enough to any one whose pursuits are directed towards improving the metallurgy of iron and steel. On the present occasion, then, I shall, to shorten the time I am occupying, merely bring forward analyses from the very best makes of malleable iron I have met with, some of these being taken from Dr. Percy's excellent work on "Iron and Steel." An armour plate made at Lowmoor was found to contain 0·104 per cent of sulphur, and 0·106 per cent of phosphorus. Now, as we have before seen, the mean values for Yorkshire pig-iron are—

| | |
|---|---|
| Sulphur . . . . . . . . . . . . | 0·052 |
| Phosphorus. . . . . . . . . . . | 0·549 |

in which case, either in the puddling or re-heating furnace, but most probably in the former, the sulphur is doubled, but the phosphorus diminished by the very great amount of 0·433 per cent. This, however, being an armour plate, is a special case, and it is highly probable that a portion of better pig-iron was mixed with the Yorkshire pigs ordinarily used at Lowmoor. The sulphur is considerably increased; it may possibly have been added from the fuel. In several other specimens of armour plates we find sulphur existing in the following percentages:—

Sulphur, 0·058, 0·121, 0·190, 0·118, 0·058, 0·104,

and phosphorus in the following:—

Phosphorus, 0·030, 0·173, 0·020, 0·228, 0·089, 0·106.

In regard to the sulphur, it is higher in the examined plates than in all the different qualities of British pig-iron except two, namely, Northamptonshire and Scotch; and since it is not in the least likely that either of these pigs were used in producing the plates, we may infer that sulphur has been added to the iron during its conversion and working into the malleable state, whilst the phosphorus is eliminated in every case to a very large extent, bringing its percentage considerably lower than in any known analysis of British pig-iron. Comparing, again, malleable iron of South Staffordshire with the pig, we have for the former:—

| | |
|---|---|
| Sulphur . . . . . . . . . . . . | 0·165 |
| Phosphorus. . . . . . . . . . . | 0·140 |

Here, also, the sulphur is increased and the phosphorus diminished to a very considerable extent, and the same result obtains generally with any other comparisons that we may make. We are therefore led to infer that during the conversion of pig into malleable iron, sulphur is added to the iron from the fuel, whilst the phosphorus is eliminated in a very large ratio. Of course, in considering the increase that takes place, we must bear in mind that the percentage in malleable iron is greater in proportion to the absolute amount of iron itself present than obtains in the pig-iron, for the reason that, in the latter case, the carbon and silicon are present, whereas in the former they are nearly eliminated.

Comparing the foregoing results with analyses of iron made by the Richardson process, the superior eliminating power of that process is forcibly striking. In the analysed samples of the iron made at the Glasgow Iron Works by that process, as I have before stated for the experiments, common Scotch pigs were used; and yet from that material we have obtained finished bar iron purer than anything that has ever heretofore been manufactured from British ores, and that, too, from pig-irons which contain the highest percentage of sulphur, and rather above a medium of phosphorus; indeed, the removal of these two elements is so nearly complete, that practically they are not found. There can be no doubt remaining that the Richardson process has effected what has never before been done in Great Britain; by it we are enabled to produce a better and purer iron from the commonest pigs than we can yet depend on obtaining continuously by the common process of puddling from the best pigs. We can save a third of the time hitherto occupied in puddling, get a higher yield, save fuel, and, therefore, cheapen the production of malleable iron.

For the last two or three months there have been several furnaces making iron by this process at Parkhead. I have a large number of the returns as to the time of puddling a charge, besides a large number of results which I have noted myself from watching the conduct of the process on several occasions; these, however, I have not had sufficient time to tabulate, but I may state that the time from the moment of charging to taking out the balls varies from one hour fifteen minutes to one hour thirty minutes, whilst, in another experiment that we made, having previously "fettled" the furnace very heavily all round, both the bridge, sides, and flue, the heat was out in one hour twenty minutes; this, without the fettling, would correspond to about one hour and ten minutes, a remarkably short time when we remember that at this forge, where very grey pig-iron is principally used, the amount of time usually occupied for puddling by the old method is one hour forty-five minutes, and very often two hours. The period of melting in the case of such pig-iron is very high. I have on several occasions noted it, and find it to vary between thirty-five and fifty minutes; this is, doubtless, due, in a great measure, to the high percentage of combined sulphur, and very probably, to some extent, depending upon the large proportion of silicon contained in it, as well as the hæmatite, a small portion of which entered into the mixture. Out of the hundreds of bars that have now been made in this manner at Parkhead from the "common mixtures," too, it is particularly important to remark that not a single bad bar has been met with. The iron works better under the shingling hammer as well as the rolls. In the puddled bars, after they have passed through the mill and are cooled, their appearance externally is frequently as smooth as good finished merchant bars, whilst the fracture shows the perfect regularity of the metal. With puddled bars of the same mixtures made in the ordinary manner, when cold and worked to the same extent, they are much more full of flaws and fissures gaping wide open at the surface, and the fractures always show much want of uniformity, while the microscope usually reveals the presence of a great deal of graphitic carbon. Puddled bars from the common mixtures will not usually bend through a greater angle than 40° without cracking right across; some of them break off quite *cold-short* before having reached that angle; whilst the best bars of such mixtures rarely, if ever, bend 45°, and usually break in half before reaching that extent of flexure; but with bars made by the "Richardson process," out of precisely the same materials, I have seen them, I may with certainty say, on most occasions bend completely round to 90° without breaking, frequently without showing a surface crack, and some specimens that have been tried were doubled up without effecting a complete fracture. Altogether, the advantages of working by this process are so great as to require no further comment from me.

*Note.*—Since writing the foregoing it has occurred to me that I should mention the now well-ascertained fact that in the puddling furnace some of the phosphorus passes from the charge into the cinder, but by no means the whole of it. This circumstance led Dr. Percy to propound his theory that still more of that element, existing in the charge as phosphide of iron, was liquated or sweated out after the metal was balled. If there be any truth in this supposition, it appears to be be confirmed by the results of the mode of working to which I have now called your attention. The balling process is of longer duration, as I have already explained, therefore greater time is afforded for this supposed liquation of the phosphide. I merely throw this out as a hint; it is rather soon yet to attempt to form a conclusive theory. That phosphorus is not got rid of by oxidation in combination with iron is certain, or it would unquestionably be eliminated in the Bessemer converter—every means hitherto tried having utterly failed to remove it.

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The President inquired whether any experiments had been made to test the tensile strength of the iron made by the Richardson process?

Mr. Day replied that the attention of Mr. Richardson and himself had hitherto been chiefly directed towards perfecting and obtaining a complete knowledge of the chemical features connected with the process, which he considered it was most important to be sure upon in the first instance, before proceeding into a train of experiments as to the mechanical qualities of the material; he had formed this opinion because it was daily becoming more apparent to those persons engaged in such investigations that when the chemical nature of a specimen of iron or steel was once known within the limits of as accurate an analysis as it was at present possible to make, that from this chemical knowledge the mechanical properties could be predicted within narrow limits of probable error. Another reason why chief attention had not hitherto been directed to ascertain exactly the tenacity, compressile resistance, the elongation or compression of the material under stress, or the various *moduli* of elasticity, rupture, &c., consisted in the fact that, with the rough and ready, although inaccurate, style of test to produce the fracture of the "puddled bars" usually employed, the toughness and ductility of the metal had shown themselves so much higher than what resulted from bars made from the same (common) mixtures of iron by the ordinary process of puddling, that it was considered the accurate determination of these values might safely be left over until after certain other processes of the experimental inquiry were further advanced. Nevertheless, he believed one or two tests had been made at Messrs. Napier's, according to instructions given by Mr. Beardmore, the results of which had been to show that the *finished* iron, both in the direction of and across the fibre, was stronger and more ductile. However, upon these mere solitary tests he was of opinion that much weight should not be placed, particularly so as the iron was amongst some of the first manufactured by the process, when the mode of working it was not so well understood as now. He did not remember the values exactly for these tests, but he had no doubt that Mr. Beardmore, who was present, would give them.

Mr. Beardmore said that the value shown by the tensional test was 27 tons per square inch in the direction of the fibre, and 23·7 across the fibre.

Mr. J. M. Rowan quite coincided with the sentiments expressed by Mr. Day, of the impossibility of removing either sulphur or phosphorus by the Bessemer process. If it had been done by the Richardson mode, it was more than Mr. Bessemer had done.

Mr. Day did not intend to convey the meaning that it was impossible to remove sulphur and phosphorus from molten iron when in the Bessemer converter. All he said was, that it had hitherto been found impossible to do so, although almost every so far available means for effecting their elimination had been resorted to. Chloride of calcium was, he believed, the last substance tried, and most persons expected, from the reports that were circulated concerning the valuable properties of this compound in the converter, that a cure for the evil had thus been found. The effect was tried, he believed, at Mr. Bessemer's own works at Sheffield, and the steel produced was analysed in this country as well as in Germany, the results of which went to show, if he remembered correctly, that, according to the analysis made by Mr. Riley, the phosphorus and sulphur were eliminated in a larger ratio than formerly, whereas the German chemist's analysis showed the very reverse. This indicated that chemists had now a good deal to learn in arriving at a process of seeking for these two elements that might be considered practically accurate; for although both substances were in all cases most difficult of detection on account of their presence in such minute quantities, yet they so materially affected the value of the mechanical properties of iron that it was a most important item in the physical interpretation of this question that the percentage should be known with precision. He, however, was amongst those men who looked forward to the time when sulphur and phosphorus would both be eliminated from the charge in the Bessemer converter, although he did not think that at present it could be predicted how that was to be done.

Mr. Ferdinand Köhn said he had listened with much pleasure to Mr. Day's paper, and the remarks he had made as to the difficulties of removing sulphur and phosphorus from iron. He thought it right to correct an opinion hinted by Mr. Day, as to German chemists being superior in making analyses for the detection of phosphorus and sulphur. He thought Mr. Day was not quite well informed on that point. The case was the reverse; for Mr. Riley found more phosphorus in the steel than in the pig-iron from which it was made. This was explained by considering that after removing certain impurities from the pig-iron the quantity of phosphorus would apparently increase, on account of the diminished quantity of the total mass. He thought it due to Mr. Riley, who is a very clever and reliable analyst in this specialty, to correct the impression which might have been made by Mr. Day's statement. With regard to the statement that Mr. Bessemer had found it impossible to make iron by his process, and could produce nothing but steel, he wished to remark that a distinction between iron and steel could hardly be maintained on any precise scientific basis. The softest qualities of steel made by the Bessemer process, whether tested by chemical analysis or judged by their mechanical properties of flexibility and malleability, showed the same minute proportions of combined carbon and the same degree of malleability as the softest kinds of iron known in the market. Boiler plates and ship plates of

Bessemer steel might now be seen at almost any first-class engineering establishment which would double up cold, and would permit to be bent and distorted to an extent equalled only by the very finest specimens of high-class wrought-iron plates. Samples of Bessemer steel were exhibited at Paris which had a smaller percentage of carbon than the average kinds of wrought-iron are known to possess. The only possible distinction he could see between iron and steel was that the former contained particles of slag between the metallic crystals, while the latter was homogeneous and free from admixtures of slag. If this definition was adhered to, he believed that Mr. Bessemer would not be very proud to assert his capability to produce iron by his process; but, on the other hand, judging from the fine quality and homogeneous character of the bars made by the Richardson process, Mr. Richardson would ultimately be forced to admit that, in some cases, the product of his process was nothing but steel. When the Bessemer process was first introduced the steel-masters maintained that the product was anything but *steel*; now it appears that iron-masters tried to say that Bessemer metal was anything but *iron*. Both statements, however, are entirely incorrect; the Bessemer process is capable of producing every variety, from the hardest steel to the softest homogeneous metal that any other mode of manufacture now in existence is capable to produce. It was true, however, that the Bessemer process was *confined to the employment of the purest qualities of pig-iron*, and for this reason it appeared to him that the Richardson process, which was applicable to the inferior classes of pigs, had a wide range of utility, and was likely to become a process of vast importance.

Mr. Day was exceedingly glad of the opportunity Mr. Köhn had afforded him of putting the matter of Mr. Riley's analysis right. Mr. Köhn had referred to the different series of materials produced in the Bessemer converter. He remembered Mr. Köhn had read a paper before the British Association at their meeting in Dundee, in which, as it appeared to him, the suggestion of indicating the continuity of the series of metals in a graphic manner by the aid of curves representing their mechanical properties was extremely valuable. This graphic representation was still further extended on the same occasion by Professor Rankine. With regard to Mr. Köhn's further remarks, purporting to show that there was no final line of demarcation between iron and steel, in theory he coincided, but for practical purposes there could be no question that it was most important to fix certain limits by which commercial transactions might be guided.

Mr. Downie asked whether in the working of the Richardson process the amount of work done by each puddler was greater than before—whether, instead of six heats, they could have eight heats per day?

Mr. Day said that was one of the objects aimed at, but the puddlers had hitherto frustrated this. He thought, however, by making the furnaces a little deeper, so that heavier charges could be employed, thereby they might get the equivalent of two extra heats per day.

Mr. Downie believed there was a difficulty in the way of turning out more, as scarcely any man could stand the labour of turning over so many charges.

Mr. Day replied that he had no doubt by the common process the present day's work was enough, but by the Richardson method the puddler's labours are considerably diminished.

Mr. R. Douglas wished to be informed of the brands, and, approximately, the analyses of the iron with which these experiments were made. Mr. Day had stated that the specimens exhibited were made from common Scotch brands; but as his interesting paper was so full of analyses, it would have been satisfactory to know somewhat definitely the quality of pigs used to produce these results.

Mr. Day replied that, on account of the great scarcity of reliable analyses of Scotch pig-irons, he could not state exactly the chemical percentage of those brands used with the Richardson process, but, referring to the analyses given in the paper, it would be found by taking the mean of means what the percentage of the impurities amounted to.

Mr. Rowan stated that the average of Scotch grey pig-irons contained phosphorus, 0·75; sulphur, 0·04.

Mr. Downie said he thought that the possession of reliable analyses was a matter of great importance. Although the evidence of analyses was difficult to obtain, yet the very differences that Mr. Day had pointed out would point to different results if different classes or pigs of the same brand and under different conditions; and unless they had the analyses of the pigs used in those experiments, they could have no correct idea of the value of the Richardson process.

The President said that the quantities of sulphur and phosphorus in the iron made by the new process was about one-tenth of that in ordinary puddled iron; so that he did not think that such an immense diminution as that could be traced to the difference in the quality of the pig-iron. He asked if Mr. Day could give them any idea of the point at which the phosphorus and sulphur became absorbed or dissipated from the iron. Was it at the time when the air was forced into the iron? The same process of injecting air was used in the Bessemer process, which, it was alleged, did not remove the phosphorus or sulphur, so that it could scarcely be at that point in the manufacture. Or were these elements taken away in the puddling process.

Mr. Day replied that the theory as to the removal of sulphur and phosphorus is, in its present state, incomplete. It was known that sulphides and phosphides of iron maintained a state of liquidity at a lower temperature than that at which the iron was formed into balls; this led Dr. Percy some years since to propound the view, that when the granules of iron were collected into balls, the phosphides were liquated or sweated out; and some experiments made at Woolwich by Professor Abel seemed to confirm this view. If this supposition of Dr. Percy's was correct, it lent great weight to the value of the Richardson process, because on account of the temperature of the furnace being higher, the period of balling was necessary longer, and in that case greater time was allowed for the liquating or sweating out of the sulphide and phosphide. One thing, however, was perfectly evident, that there was some influence at work with the Richardson process that was not present in so large a degree by the common process: it effected the removal of sulphur as well as phosphorus, as a reference to the analyses given in the paper would clearly show.

Mr. W. M. Neilson thought it would have been important if a drawing of the furnace where the experiments were made had been exhibited. He could not see how air blown in the same way could have a different effect in the Richardson from the Bessemer process. He would like to know what was the difference in the amount of coal used in the two processes.

Mr. Day replied that air was not blown in in the same way, at the same time, nor for so long a time, nor for the same object, in Richardson's as in Bessemer's process, and that a saving in fuel was effected by the Richardson process.

Mr. Neilson said it was well known that there was a considerable amount of sulphur given off by the coal in the furnace, and he suggested whether it might not, in some degree, account for the smaller quantity of sulphur found in iron made by the Richardson process that it was a shorter time than usual in the furnace. Also, might not the current of air which passed over the top of the coal in the furnace prevent the iron from imbibing the sulphur. It was rather a mysterious thing, and being so, they could not exactly believe it. Probably if they got the drawing of the furnace, and more explanation of the perfect process, they would understand it better.

Mr. Beardmore said an ordinary reverberating puddling furnace was employed. The air was blown through the iron near the bottom.

Mr. F. Köhn concurred with Mr. Day's statement, that the theory of the metallurgical processes now under consideration was not very perfect. There were, however, sufficient experimental data on record for forming at least an approach to an explanation of the difference of results obtained by the Bessemer and by the Richardson process. He would first of all refer to Mr. Neilson's remark about the supposed diminished absorption of sulphur from the coal in the puddling furnace. This explanation, although plausible in itself, would not suffice for explaining the actual removal of sulphur already contained in the pig-iron before its being charged into the furnace, and which the experiments had shown to take place in such a large measure. Experiments had been made by Dr. Crace Calvert, of Manchester, Professor Wedding, of Berlin, and others, to ascertain at what period of the puddling process the sulphur and phosphorus were removed from the iron and driven into the slag. Samples of iron were taken out of the furnace during a charge in intervals of a few minutes, and particularly at those moments when any of the vital changes in the puddling process occurred. The analyses of those samples showed that the sulphur and phosphorus were removed principally during the early stages of the puddling process—that these elements combined with oxygen and formed sulphates and phosphates or salts, which formed a portion of the slag. It seemed probable from other experiments on record that, at a higher temperature, such as that which follows the "boil" in puddling, or such as existed in the Bessemer converter, the liquid iron in contact with the slag had the power again to reduce those salts from the slag, and to form sulphides and phosphides of iron. In the Bessemer process the whole liquid contents of the converter, including these sulphides and phosphides, are turned into the casting ladle, and finally into the ingot moulds themselves; there is, therefore, no opportunity given by this process for a separation of the metal from those noxious substances. In the puddling process the stage of "balling" affords such an opportunity. It is well known that the phosphides of iron are liquid at a much lower temperature than that at which wrought-iron solidifies or "comes to nature," in the terms of the puddlers. It seems also likely that some sulphides of iron have a similar property. An experiment recently communicated to him by Mr. James Addie, of the Langloan Ironworks, appeared to give evidence on this point. In certain kinds of pigs a peculiar speck of a different colour from the rest of the iron had been noticed when fracturing the pig through its centre, this speck again occupying the centre of the fractured surface. Mr. Addie had a portion of this material drilled out of the centre of a pig, and the analysis showed that this portion contained a much greater percentage of sulphur than the rest of the iron taken from the same pig. This seemed to show that the pig-iron solidified at a temperature at which the sulphides mixed with it remained liquid, and that these latter therefore accumulated in the centre of the solidifying mass, and remained liquid there until the temperature fell below their own point of solidification. Although it did not appear prudent to found a theory upon a single experiment, he believed that the general tendency of the evidence was in favour of the assumption that both sulphides and phosphides of iron remained liquid at the temperature of the boiling process. Taking this for granted, it would appear that the mechanical process of balling, which consisted in collecting and pasting together the solid particles of iron, would effect a separation of the metal, not only from the slag, but also from those liquid sulphides and phosphides; and the iron formed into a ball, and freed from the adhering mass by the subsequent mechanical operations, would therefore contain only a proportionally small amount of sulphur and phosphorus. He did not hold up this attempt at an explanation as a precise and well-established theory, but he thought it at least sufficiently plausible to be of some utility in the present state of existing knowledge on this subject. He believed that Dr. Percy was the first to point out the peculiar function of the balling process in connection with the removal of sulphur and phosphorus from the iron.

Mr. Beardmore said they saved a quarter of an hour on each heat. The yield was about the same as by the ordinary process. The iron was very uniform and improved. Although they saved a quarter of an hour in each heat, yet the men would not give them more heats per day than previously. The tensile strength and the ductility were greater.

Mr. Day remarked that if the elongation was greater, that was a very important piece of information, as the *work* necessary to produce fracture showed at once a much higher value.

The President said it was very evident that when they came to compare one process with another, engineers did not look at the question from a chemical point so much as the mechanical—the question with them was what work the material would do; and it would be well if some experiments were made to bear upon that point in the matter before them.

Mr. J. M. Blair asked if the Richardson process would cheapen the price of iron? He expected, as one of the practical results of this new process (seeing that such a saving of time and fuel was effected), the price of iron would be reduced; but Mr. Beardmore did not seem to admit any appreciable saving.

Mr. Beardmore said an inferior pig-iron could be used in the manufacture, which would tend to cheapen the process.

Mr. Day replied the correct answer to Mr. Blair's question was—that out of common pig-iron, puddled iron was now made by the new process equally strong as with that hitherto made from the best brands, by the common method of puddling from the best pigs. Chemically speaking, the new iron is considerably purer than that made from the best pigs by the old process. The economy thus brought about was therefore unquestionable.

Mr. R. Douglas said he was not very conversant with the process of puddling; but to his mind it was not at all satisfactory that they should have statements so widely varying from Mr. Rowan and Mr. Day, as to the sulphur and phosphorus in Scotch pig-iron, when the Richardson process claimed to accomplish largely the elimination of these elements. He would like to have analyses of the particular irons used in the various experiments.

Mr. Day stated that the mixtures under the experiments have been seven-eighths of No. 4 Scotch grey forge pig, and one-eighth of red hæmatite, the chemical value of which, in respect of phosphorus and sulphur, could be found in the analyses given in the paper.

Mr. Downie concurred with a good deal that had been said in respect of those special experiments. He thought that, as a class, engineers had too long neglected to give due attention to chemistry; and he was of opinion that it would be well if the analyses of iron experimented upon were added to the paper yet. Mr. Köhn had given them a theory of the manner of the change that took place in the iron, and if Mr. Beardmore could supply analyses of the iron he was using, it would be of great importance. He looked upon the Richardson process as a great improvement upon the old system.

Mr. Day replied that, on account of the process being so recent, it had not been possible to collect together all the information desirable; and it must be remembered that, by reason of the fact of the theory referring to the metallurgy of iron and steel being yet imperfect, it was difficult to produce an exhaustive explanation of such a subject at this early stage. No question, however, could remain as to the value of the great facts which had already been elicited.

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## EXTRACT FROM A PAPER ON "HOT BLAST FURNACES"

(Read by Mr. Whitwell, before the Cleveland Institution of Engineers, April 28th, 1869).

### Hot Blast Apparatus.

**Fire Brick Stoves.**—The plan known as the regenerative principle, first patented and made public by Robert Stirling, in 1817, is the basis on which all other systems of fire-brick stoves are founded. Stirling patented the heating of airs, gases and fluids, by the agency of airs, gases, or fluids by means of passages formed of brick, metal, stone, or any suitable material re-adapted to the degree of heat required, and after showing how his system could be applied to the manufacture of glass, pottery, &c., or any case where great heat is required, left it at that point.

No. 2861.—In 1856, Mr. Frederick Siemens patented improvements in furnaces. The hot air from the furnace is passed through chambers containing refractory materials presenting a large surface, and air to support combustion in the furnace is passed through the same chamber, in the same or opposite direction alternately with the hot air, so as to become heated. Two such chambers may be used, the flame passing always through one, and air through the other. The alteration in the current is produced by valves. The chambers may be so arranged that the product of combustion shall pass through one passage and the air through another at the same time, such passage being heated by conduction only. Such passages may be made *zigzag* or tortuous.

No. 1404.—In 1857, May 19, this application of the regenerator is patented by Edward Alfred Cowper. The air, under pressure, is heated by being passed through regenerators, which consist of air-tight cases of iron lined with fire-brick, or other non-conducting material. A number of tortuous passages are made for the air, and another set of passages in close contact with them serve for the products of combustion. Two regenerators may be employed, and the air and products of combustion passed through them alternately. The waste heat of a blast, or other similar furnace, may be used to heat regenerators arranged as above described. The regenerators are filled with fire-clay or other refractory material in lumps. The specialty consists in enclosing the regenerator in an air-tight case. Mr. Cowper at once arranged his stove for heating the blast for blast furnaces by means of the waste gases. A small trial pair were erected by Cochrane and Co. at Ormsby Iron Works, Middlesbrough, and, though only supplying one tuyere, produced good results in the general working of the furnace.

The firm then proceeded to erect two stoves 19 feet in diameter by about 18 feet high, with domed tops. Within an air-tight casing, lined with 18″ of brick-work, a centre shaft 4 feet diameter was constructed, the annular space surrounding which was filled with bricks in the form of a regenerator, beneath which circular flues connected with the chimney were constructed. When the stove was being heated, the gas was admitted by the centre shaft, duly mixed with air, for combustion ; arriving at the top, it descended through the open brick-work to the flues, whence it was conducted to the chimney. This continued till a stratum, 3 feet or more, of brick-work was heated red hot—the rest shading off to blackness. When sufficiently heated, the blast was turned on.

Whilst these stoves were in course of erection, two pairs of stoves were erected at Port Clarence, and heated by the blast furnace gases. At first the heats were excellent, zinc and even antimony being freely cut by the blast which issued at a red heat; but after two or three month's trial, the stoves became gobbed or choked with the dust of the blast furnace gas, and after ineffectually trying to overcome the difficulty by the application of circular fire-brick tubes, in place of bricks, the plan was abandoned. In the meantime, the stoves were nearing completion at Cochrane and Co.'s, at Middlesbrough, and in order to avoid the unfortunate *contretemps* at Port Clarence, the firm decided to erect Siemens's gas producers wherewith to supply the patent stoves with a pure gas. This plan answered well, a good heat was gained, and compared with a cast-iron plant of the day, I am informed by Messrs. Cochrane and Co.'s printed circular, that these stoves produced a saving of 5 cwts. of coke per ton of iron made. But whilst this plan answered, the furnace gases costing nothing were being wasted, and no means was yet discovered of perfectly cleansing them of the dust, so as to make them fit to use in a Cowper's stove, which, whilst eminently calculated to absorb all the heat resulting from the combustion of the gases, formed at the same time a most perfect dust trap, which could not be cleansed without pulling down the stove.

We now come to Stirling's principle as applied in the hot blast stoves, brought out by the writer.

One morning in April, 1865, whilst on his way to the Thornaby Iron Works, thinking over Morton's stove and the best way of making the pipes near the fire stand the heat, he struck on the idea of making Morton's stove in fire-brick, and at once sketched it down in his note-book in plan, section, and elevation, which bear not the slightest resemblance to either Cowper or Siemens's well-known application of the regenerative principle. The heating material being constructed in the form of the stove, was supplied with doors and movable lumps at the top, whilst cleansing doors were also provided at the bottom of the sides for the purpose of removing dust scraped from the vertical surfaces. In this way the top door gave access to four surfaces, the dust being removed at the valves at the bottom of the sides of the stove. The first form was rectangular in order to gain all the space possible, but this, after trial by a pair of stoves, was replaced by the circular plan, the principle being the same.

In this apparatus it was proposed to admit the air to be heated, as well as to permit the egress of the heated products of combustion on the one end of the stove, as also to form the outlet for the hot blast, and the gas inlet in a somewhat similar way, the latter to be lined out with fire-brick; but it was soon seen that the heat in the blast would be so great that no ordinary slide valves could be depended on to remain tight for any length of time, and hence the valve was adopted, consisting of a cast-iron shell 14″ diam., and with hollow spindle, through which water circulated, also to have a water seat, whereby the valve faces would always be preserved intact. The same plan had already in principle been adopted at Cochrane and Co.'s, though in a different manner.

It was now decided to put up a trial pair of stoves at Thornaby Iron Works. The site had been occupied by an oval stove, and, owing to the existing arrangement of blast and gas tubing in full work, these stoves were of necessity of a rectangular form, which is, of course, by no means the strongest shape or cheapest in construction. The casings were of $\frac{3}{8}$ plate, with butt joints covered by a tee iron 5″ × 4″ × $\frac{1}{2}$″. It was foreseen that the sides, ends, and top would give to a certain extent till the strain acted on the section of the iron, when all further movement would cease. By a slight modification of the arrangement, the blast in this instance, instead of passing over and under each wall alternately, was caused to ascend a wall, pass over the top, descend the other side, and then passing under the centre longitudinal wall, to ascend and descend the next wall, whence again, passing under the centre wall, the process was repeated. By this course, one passage having a minimum area of 4 feet × 9″ or 3 square feet, but 240 feet long, the circumference of the passage being 9′ 6″, was secured, and through this passage, the bends of which were made one and a half times the mean area of the conduit, the blast and gas were directed in turn. The amount of heating surface in each stove was therefore upwards of 2300 square feet, of which 1600 square feet were to be heated to the point of redness, the remainder shading off till the products of combustion passed off at a low temperature. When a stove had been the proper length of time in blast, there were to be still 700 square feet of heating surface red-hot, and thus the blast would never be below the point of redness. The top cleaning doors were made with a plain joint luted with fire-clay, each door 4 feet × 2 feet, being held in place by a bridle and two toggle bolts. The bottom cleaning doors had mitre-faced joints, each being in like manner held in place by a toggle bolt and bridle, which fell below the seat when opened for cleaning. After the stoves started, it was found necessary to provide a water seat for the gas valves, beyond which there have been no material alterations made. Owing to the heated blast, which outside the stoves heats its metal conduits to a bright red temperature, having to travel about 50 feet through old metal connections before reaching the furnace, much of the heat was lost—the blast which at the stove cut zinc in two seconds only giving an average of seven at the tuyere. The old connections are now being replaced by wrought-iron tubes lined with fire-brick, which being in internal diameter 10″, with 9″ of fire-brick surrounding, will conserve the heat till it reaches the tuyere.

We now come to the latest and simplest form of fire-brick heating stove. Whilst the above stoves were being tried at Thornaby, Mr. Cowper was not inactive. He designed and patented a dust-separator, consisting of a tube about 6 feet wide, 8 feet high, by 60 feet long, more or less, with iron trays through the whole length, from 3 to 4 inches apart; this, it was held, would perfectly cleanse the gas from the dust—the theory that if gas travel slower than 3 feet per second, the dust contained in it will be entirely deposited on the trays—such a cleanser would only cost about £1500 per furnace.

Almost at the same time we find a patent by Mr. Charles

Cochrane for making cleansing apparatus of shelves of iron, over which the gas was forced to pass consecutively, which would infallibly remove 95 per cent of the dust. A trial of the latter was made with good results at the outset, but as the quantity of cleansers were not sufficient, the quantity of depositing shelves was greatly increased, and again tried; for some weeks it answered well, till at length after about four months' trial, the stoves were gobbed up with the dust that passed the cleansers, and the furnace was blown out. So convinced, however, were Messrs. Cochrane and Co., of the immense advantage of having an apparatus that could not be melted or burnt, or overheated, that in laying out their new furnaces they erected a still larger plant of cleansers, and two large Cowper's stoves, about 26 feet diameter by 20 feet high, and foreseeing that the time might come when the stoves, notwithstanding the cleansers, might want cleaning out, such cleaning involving every heating brick being taken out and scraped separately, and a stoppage of such stove for from six to nine weeks, they added a third stove of still larger proportions to replace the stove so laid off.

In the meantime, the directors of the Consett Iron Company (Limited) determined to make a trial of a fire-brick heating plant on the writer's patent, and apply the same to one of their furnaces; for this purpose an old furnace with its stoves was swept away, a large plant of pistol pipe stoves, working to No. 6 furnace, at the Consett works, pulled down, and on the site, four circular stoves, each containing 9000 square feet of heating surface, making 36,000 feet in all, were erected. Owing to existing arrangements in operation, the stoves had to be worked in to the site, and hence symmetrical arrangement could not be secured. They were, however, close to the furnace, and any loss by radiation carefully guarded against. The principle of the stoves is the same as at Thornaby, only they are circular in form. Sufficient space is allowed at the hot end for the gas to ignite, after which it is conducted through the stoves by two conduits, which are 9″ broad, by an average of 10″ long; the total length of the passage being 300 feet. In order to guard against the centre of the stove being cold, a certain quantity of gas is conducted by small openings on the inner side of the outer longitudinal walls, by which means the centre, as also the outer parts, are heated alike. Of the 300 feet of travel, about 200 feet are heated red-hot, as is seen through eye pieces inserted through the casing and shell, by which means the state of the interior of the stove is always commanded. This corresponds to about 6000 square feet of heating surface at a red glow, and the remainder, 3000, shading off till the products of combustion pass to the chimney at a temperature of about 400°. When heated to this point, the gas inlet and outlet are closed, as also the air valves, and the cold and hot blast valves are opened. The blast now enters, and, passing over the coldest walls, is gradually heated till it is as hot as the brickwork; after which it takes up no more caloric, and issues by the hot blast valve through tubes lined with 9″ brickwork, and enters the furnace at a red heat. By this plan two stoves are on and two off, and at no time is less than 2000 square feet of heating surface below a red heat, so as to secure uniformity in the temperature of the blast. In the construction of the stoves care was taken to leave a space of 1″ all round, between the brickwork and the wrought-iron shell, which was filled with dry clay as the work proceeded, so as to allow for any expansion of the brickwork; the same allowance was made at the top, which was also filled in with clay. Each brick was carefully laid under inspection, the joints being perfectly flushed up with fire-clay. At the hot end the walls were constructed of half ganister and half fire-clay bricks, the transverse walls being 7″ thick, and built in lumps 12″ × 7″ × 3″, which made excellent work. The first transverse wall at the hot end was 14″ thick, with an air course 2 feet × 4″½ in., duly supported with heaters built in, communicating with a 12″ valve on the outside, so that the air for promoting combustion should be red-hot ere it mixed with the entering gas, and thus develop the most intense heat. Within the gas inlet an argand burner was constructed of Stourbridge clay, also fed by a 12″ air valve, in order that, between the two systems, the greatest temperature should be developed; the Stourbridge burners, however, fell to pieces the first shift, as they would not stand alternately being heated red-hot when the stove was on blast, and then when on gas, having the cold air for combustion passing through them; a burner was then constructed of brickwork, which answers well, the heat developed being very great, the ganister bricks being thoroughly glazed at the hot end; indeed the stove-minders say that with the heated air and the burners they can develop a most intense heat. The brick lining is 18″ at the hot, and 14″ thick at cold end, and in order to accumulate more heat, as a reservoir, the second and third transverse walls are 9″ thick. The hot blast gas and chimney valves are here shown. The former is in the form of an inverted mitre valve, cast hollow, with hollow spindle, raised by a chain wheel. Through the valves, as also the seats, water circulates so as to preserve them, care being taken to prevent any hot blast striking such cooled surfaces. The bonnet within which it works is lined with brickwork, and 2′ 6″ main communication with the blast tube round the furnace has an air way of 12″ diameter, with a lining of 9″ thickness, to guard against radiation. This crossmain has also an expansion joint of metal, rivetted to the tube, so as to allow for all changes of temperature. The hot blast is carried across the expansion joint by a piece of 12″ pipe laid in the brickwork, with room also allowed for expansion. The gas inlet valve, 22″ diameter, as also its seat, has water circulating through them, and below these is a slide valve "faced," so as to regulate the supply of gas, as also at once to detect any leakage of blast when the mitre valve is shut, and prevent such from mixing with and igniting the gas in the gas flue. In like manner, the chimney valve is 2′ 2″ diameter, with a plain mitre face, but fitted with a water seat as a precaution. The draught is regulated by a slide valve, not faced, which also detects any leakage, should the mitre valve be off its seat through dust. In order to ensure this point being rectified, a crosshead on the spindles of the gas and blast and chimney valves admits of their having half a turn round given them when on their seats. Leakage through the hot blast valve is detected on each turn by opening the first cleaning door on the side. This also applies to the cold blast inlet valve. The cleaning of these fire-brick stoves forms one great feature in them. The gas having been shut off, the chimney valve is slightly opened in order to carry the heat downwards, and the first top cleaning door at the hot end, which is supplied with springs in case of an explosion, is taken off, the lumps protecting it are lifted, and scrapers with 1″ tube handles are screwed together, and the walls scraped up and down, the dust falling to the bottom. The first compartment being cleaned, the door is replaced, luted with fire-clay paste, and screwed down, and the same process repeated with the other doors in rotation, whilst the walls are red-hot. Of course hand leathers and tongs are needed, and a spare scraper is at hand to use by turns. The top being made good, the side circular doors are opened, and the dust raked out with coal-rakes. The whole operation does not take above three or four hours, and the stove then goes on for two or three months, more or less, depending on the amount of dust deposited on the walls. As will be seen, the cold end walls at the end of a turn are 400° hot; the cold blast is then admitted, and striking these surfaces, gradually robs them of their caloric, till at the end of the turn, say in two hours, they are much cooler, the blast, when in full work, having been flowing over them at the rate of 4-5000 cubic feet per minute. When again the stove is put on gas, the products of combustion give their heat to the walls, and thus the greatest economy is attained in the use of the gas. To so great an extent do the walls absorb the heat, that on one occasion, it being desired to cool down a stove, the blast was kept on some hours, till at the hot end it was apparently black. On being laid off for an hour the heat came out of the interior of the walls and heated the stove red-hot; it was then put on blast for two hours, and this was afterwards twice repeated, till the caloric was at length taken up. It will thus be seen that in construction and operation these stoves are very simple, the difficulty of cleaning is overcome, and hence there is no necessity for an expensive apparatus of cleansers, which add enormously to the cost of the plant. The total cost of the stoves at

Consett is not more than has been spent over cast-iron stove plants, of the most recent date, whilst the heat is greatly superior and the economy of coke proportionately greater. Should any repairs ever be needed, they amount at most to a few bricks and a man half a day to put them in, but so far as can be seen the fire-brick hot-blast stove is certain to have a good life from the nature of the material made use of.

## A NEW METHOD OF PRODUCING CAST-IRON.

### By M. Ponsard.*

The metallurgy of iron has, during the last ten years, made incontestable progress, both in France and elsewhere; we must, however, acknowledge that the large quantity of fuel required for the extraction of the metal from the ore, prevents the production of cast-iron, wrought-iron, and steel at moderate prices.

The exorbitant cost for fuel which the present mode of treating iron ore necessitates, is in consequence of the principle that *the production of cast-iron is possible only in blast furnaces.* This principle has been accepted as an axiom by the iron-smelters of all countries, and is the reason why all improvements and economies are made to apply to the installation of blast furnaces and to the utilisation of the heat created in them.

No attempt has therefore been made to avoid the immense loss of heat which blast furnaces give rise to by employing another apparatus, although blast furnaces are essentially defective, for the reason that the extraction of 1 ton of cast-iron from the ore necessitates the consumption of 1500 kilos. of coke, or about 3000 kilos. of coal; this quantity of carbon is much larger than that indicated by theory.

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* Comptes Rendus des Séances de l'Académie des Sciences, Paris, 19 Juillet, 1869.

In consideration of all the inconveniences which attend the above-mentioned furnaces, I have tried to replace them by a metallurgical apparatus, which is more simple, more easily managed, cheaper, and, at the same time, admits of the production of cast-iron more or less carbonised, as may be desired, and with a considerable economy of fuel.

These improvements in the treatment of iron ores are obtained by separating the carbon which reacts chemically (*agent chimique*) from that which is burnt for producing the heat (*agent calorifique*).

My new process is carried out in a gas reverberatory furnace, which allows of the production of the highest temperature. On the sole of such a furnace I place vertically a number of fire-proof crucibles 20 centimetres in diameter and 1 metre high. The upper parts of the crucibles are fixed into openings with which the furnace roof is provided for the purpose, so that the mouths of the crucibles are in the open air, thus allowing an easy and continued charging. The lower part of the crucibles is perforated, and rests upon the furnace sole, which is furnished with gutters sloping to a basin in the middle of the furnace.

Each of the crucibles is charged with a mixture of ore, flux, and carbon; the latter substance is, however, employed only in sufficient quantity (about 12 per cent) to induce the chemical reactions, that is to say, the reduction of the ore and the carburisation of the metal.

The furnace is gradually raised to high temperature, and fifteen hours after the charging of the crucibles I have extracted, through a tapping hole, about 1000 kilogrammes of cast-iron of excellent quality. Twelve hours later I have again tapped off the iron, and continued the operation until I was enabled to make a correct calculation of the consumption of fuel. I thus found that, by this process, and owing to the high temperature, the ore was very rapidly reduced, carburised, and melted, at a consumption of only 1000 kilogrammes of coal per ton of cast-iron, whilst blast furnaces consume about three times that quantity.

The vast importance of this result has induced me to call the attention of the Academy to my new process.

The result shows :—

1. That it is possible to produce cast-iron at a considerably smaller consumption of fuel than that necessitated by blast furnaces.

2. That the exterior heat of the flame is sufficient to produce the chemical reactions, and to melt the metal. For producing the temperature every kind of gaseous fuel (produced from mineral coal, brown coal, peat, wood, and also from hydrogen and mineral oil) may be employed. As the heating carbon (*agent calorifique*) does not come into contact with the ore, the metal produced cannot be modified by it.

3. It is possible to produce at will metal more or less carburised, according to the quantity of carbon mixed with the ore.

The samples which I have the honour to lay before the Academy show the varieties of metals which may be produced by the new process; they also prove that the quality of the iron is unexceptionable.

## THE SEPARATION OF PHOSPHORUS FROM IRON.

At a meeting of the Liverpool Polytechnic Society, held at the Royal Institution in May, 1869, Mr. Hargreaves read a valuable and interesting paper upon this subject, of which the following is a synopsis :—

The manner in which this separation was effected was yet a disputed subject; the writer was, therefore, in the position of a controversialist, advancing views which were not generally accepted by authorities on that subject. But, having been led by circumstances rather than choice into this department of chemistry, he was induced to examine the question for himself without reference, and, indeed, in the first instance, without much acquaintance with the opinions of his predecessors in the same field of enquiry, except that general acquaintance with the subject which every chemist is expected to have.

The apparent anomalies which were shown in the results of different modes of reducing cast-iron into malleable iron at first struck him as demanding investigation. For instance —Why should not the Bessemer process be as effective as puddling to remove phosphorus? Mr. Bessemer, in elaborating his process, tried to render it analogous to puddling by the addition of oxide and silicate of iron to the converter, but this failed, and so far from removing any notable proportion of phosphorus from the metal, the furnace cinder, if it contained phosphoric acid, would transmit its phosphorus to the metal. And not only was this the case in the Bessemer converter, but, under some circumstances, the normal reaction was reversed in the puddling furnace itself, and iron comparatively or entirely free from phosphorus was contaminated with this impurity by the reduction of phosphate of iron present in the "fettling" of the furnace.

This was one of the many instances in the iron manufacture where the direction of the reactions was altered or reversed by varying circumstances, and it was only by a knowledge of what these circumstances were that the reactions could be controlled by the will of the operator instead of by accident.

The reactions which occurred in the puddling furnace refinery and Bessemer converter—and to these might be added the process lately introduced by Mr. Ellershausen, in the United States, and when oxidising salts, such as the alkaline nitrates, were used as the oxidising agents—were not caused by the diffusion or solution of the reagents within each other so much as by contact of the surfaces of the reagents. Phosphide, silicide, and carbide of iron were dissolved and intimately diffused through each other and through fused metallic iron; and fused silicate, phosphate, and oxide of iron were also soluble in each other, but not in the former materials.

**Puddling.**—The fused cinder and iron in the puddling furnace were not dissolved in each other, but were kept mixed together by the rabble of the puddler, and by the action of the evolved gases, which prevented the fluids from separating by reason of the difference in their specific gravities.

The simplest illustration of this mixture was a mixture of oil and water, which might be mixed together but not diffused in the form of solution. The chemical action of the cinder upon the iron took place only at the points of contact between the cinder and iron ; sulphide of iron was, however, soluble both in the cinder and in the fused iron. This surface action was the cause of many of the apparent anomalies before mentioned. Phosphorus was readily removed from cast-iron when free oxide of iron was present in large excess, but when the oxide was all or nearly all in combination with silicic and phosphoric acids, the carbon in the cast-iron reduced the phosphate to phosphide. The reduction of phosphate was much more rapid when the fused cast-iron contained a large proportion of silicon. When cast-iron containing silicon was fused in a close crucible with tap cinder containing phosphate of iron, the oxide was reduced to metal and the phosphate to phosphide. The phosphate was not reduced so rapidly as the free oxide. There was little evolution of carbonic oxide, and if the silicon was in excess, the whole of the free oxide was reduced to metal, except what was necessary to form a base to combine with the silicic acid produced by the oxidation of the silicon, and the phosphate was reduced to phosphide.

If the free oxide and phosphate were in excess of the quantity needed to oxidise the silicide, the carbide began to part with its carbon, and effervescence (owing to the evolution of carbonic acid and carbonic oxide) began. Here, also, the free oxide was more rapidly reduced than the phosphate. If the carbon was in excess, all the free oxide was reduced to metal, and nearly all the phosphate to phosphide, and no doubt with a sufficiently long exposure to heat even that slight trace would disappear. If, however, a large excess of oxide of iron was used, the phosphorus of the phosphide of iron was oxidised at the expense of the free oxide, which was reduced to metal, while the phosphoric acid combined with another portion of free oxide. The phosphorus in the iron thus decreased, while the phosphoric acid in the cinder increased. The removal of phosphorus was also very much facilitated by a current of air upon the surface of the cinder, in consequence of the cinder being kept in a high state of oxidation.

**The Richardson Process.**—These results indicated that the process introduced by Mr. Richardson was valuable, chiefly so far as it effected the rapid oxidation of the silicide of iron, thus preventing the reduction of phosphate of iron in the fettling to phosphide. And practice on the working scale confirmed this, and the process was most valuable when the lining or fettling of the furnace consisted of materials containing phosphoric acid. When, however, the lining consisted of materials free from phosphoric acid, the advantages of the process were not so apparent.

The use of "fettling" free from phosphoric acid and with little silicic acid, favoured the separation of phosphorus, especially if the iron contained a large proportion of carbon and little or no silicon. The silicic acid in the bath of fused cinder should be no more than was necessary to give it a sufficient degree of fusibility.

**Siemens-Martin Process.**—In making steel from irons rich in phosphorus, such as those of North Yorkshire and Northamptonshire, by fusing malleable with carbonaceous iron—the same as is done in the Siemens-Martin process, for instance—it is requisite that the malleable iron should be as free as possible from phosphorus. To effect this it was necessary to continue the action of the oxide till all or nearly all the carbon was removed, and it was not till then that the phosphorus was reduced to a sufficiently low proportion to fit the iron for subsequent use in the manufacture of steel. The malleable iron was then fused with a carbonaceous iron free from phosphorus, such as Swedish and hæmatite pig, or with spiegeleisen, a cast-iron rich in carbon and manganese. The Siemens-Martin process was now being successfully applied to the manufacture of cast-steel from Cleveland iron.

**The Bessemer Process.**—The Bessemer process did not favour the transference of phosphorus from the metal to the cinder or slag, but, on the contrary, if cinder containing phosphoric acid were added to the materials in the converter, the phosphate of iron would be reduced to phosphide and taken into solution by the metal. Any free oxide or phosphate of iron that might be formed at the bottom of the converter would be nearly all reduced to metallic iron and phosphate of iron before reaching the surface, and any free oxide or phosphate that gets to the surface was reduced by the ascending currents of carbonic oxide, and by the carbide of iron which mixed with the slag or cinder. A trace of phosphoric acid might be found in the slag, but it was too small to practically affect the percentage in the finished product. The slag consisted essentially of monobasic silicate of protoxide of iron, with a very small excess of free oxide. The Bessemer process produced a greater yield of iron or steel from a given quantity of cast-iron, because circumstances were less favourable to the oxidation of the metal, and indeed were such as to effect the rapid reduction of oxide added to the converter. The same causes which prevented oxidation of the iron also prevented the oxidation of phosphide of iron into phosphate. The evident remedy for this was to make the process precisely analogous to the puddling operation by maintaining in the slag a suitable proportion of free oxide of iron, and to do this the cinder should be re-oxidised from the surface so as to prevent the reduction of any phosphate that may be got into the cinder, and also favour the formation of phosphate by the action of free oxide of iron, and thus favour the accumulation of phosphate of iron in the slag. Since the Bessemer process excited attention by its brilliant success, many attempts have been made to remedy the one prominent failure which has just been referred to. Some of the proposals had been of a very absurd character. The favourite scheme was to form volatile compounds of phosphorus, which could be expelled along with the heated gases from the converter. Several persons had proposed—and the proposal had been repeatedly secured by patents—to pass currents of hydrogen and carbide of hydrogen through the converter, in the hope to extract the phosphorus in the form of phosphide of hydrogen. Carbonic acid and carbonic oxide have also been proposed in the hope that the carbonic acid and carbonic oxide might yield their oxygen to the phosphorus, and form phosphoric acid, which should either combine with the slag or be expelled with the hot gases. These persons evidently forgot that the two gases were already formed in great quantity in the latter part of the converting operation. Others—among whom was Mr. Bessemer himself—had tried to expel phosphorus in the form of chloride by injecting chlorine and hydrochloric acid, evidently in ignorance that the iron alone would be attacked by the chlorine and expelled as volatile chloride of iron. Alkalies and their salts, including nitrates, had been proposed to be added to the current of air. These substances facilitated the separation of sulphur more than of phosphorus, but alkaline phosphates not being so readily reduced, favoured the separation of phosphorus from the metal and its accumulation in the slag. The alkaline phosphates were also reduced in the Bessemer converter, though not so rapidly or so completely as phosphate of iron.

Another patentee proposed to allow the phosphide of iron to separate from the fused steel by keeping it fused long enough to allow the phosphide to rise to the surface, like so much cream on a pail of milk, and then skim off the phosphide—a process very much akin to that of allowing the sea to stand still till the brine settled to the bottom, and then skim off the fresh water from the top. By others it has been proposed to take advantage of the fusibility of the phosphide and separate it by crystallisation. To those who had any experience in separating other metals by this method, at temperatures considerably lower than the melting point of steel, it required no great powers of calculation to prove that the consumption of fuel alone must cost more than the steel was worth.

**The Hargreaves Process.**—Phosphorus was readily removed by the use of alkaline nitrates, but the same reactions which occur in the puddling furnace also occur in a modified form in this process. Till the silicon was in great part removed, a mere trace of the phosphorus found its way into the slag, and if the nitrate was mixed with a compound rich in phosphoric acid, and only a sufficient proportion of nitrate used to remove a part of the silicon, a great part of the phosphoric acid was reduced, and the phosphorus transferred to the metal; but when suitable iron was used, free from silicon, the phosphorus was readily separated, and a steel containing not more than ⅛th per cent of phosphorus could be readily produced from Cleveland iron, which is peculiarly rich in phosphorus.

**The Ellershausen Process.**—In this process, which had been described to the Society by Mr. Lander, the phosphorus was apparently removed by the molecular motion of the phosphide of iron in the cast-iron, which was disseminated in minute grains among 40 to 60 per cent of oxide of iron. He had never had an analysis of the iron, but from what he could learn of the matter from others who had worked the iron produced by it, its properties were not consistent with the presence of any considerable amount of phosphorus. He had had a description of the process from a correspondent in Nova Scotia, who describes it as forming a conglomerate of cast-iron and oxide of iron. The same person informed him that it was suggested to Mr. Ellershausen by a description of his (Mr. Hargreaves's) process for using oxide of iron and nitrate of soda. The mode in which Mr. Ellershausen had worked out the process was quite original and very ingenious. Should the results of analysis confirm the conclusions arrived at from the description of the iron made by the process, it would still further substantiate the deductions made from his own experiments.

**The Refinery.**—The reactions which occur in "running out fires" were almost analogous to those occurring in the puddling furnace, elements existing in the cast-iron were oxidised by jets of air upon the surface. The coke exercised some reducing effect upon the cinder, but this reducing action was too slow in its operation to neutralise to any great extent the oxidising effect of the air currents. The silicide of iron was first oxidised to silicate, and a portion of the metal and phosphide of iron were oxidised also, giving rise to free oxide of iron and phosphate of iron. Its principal value consisted in furnishing an iron almost free from silicon, which, when decarburised in the puddling furnace, allowed the oxidation of the phosphide of iron to take place more readily than when silicon was present in the iron, and formed a cinder rich in free oxide of iron, which still further favoured this separation of phosphorus from iron.

## THE RADCLIFFE PROCESS.*

THE history of the iron trade is remarkable as being a record of startling innovations on existing methods of manufacture. There has been, strictly speaking, no such thing as slow progress or gradual advancement in its career. Every development has followed on the adoption of a novel system of producing finished iron from the ore; and within certain limitations sufficiently obvious it may be stated that each new process has sprung into existence almost perfect, and tremendously powerful for good. We need not go back further than the days of Cort. The invention of the roll train within a couple of years practically revolutionised the manufacture of iron. Then came Nasmyth with the hot blast; then came the steam hammer; and, finally, the Bessemer process. In the space intervening between the introduction of each of these inventions and that which had gone before, the iron manufacture stood still. Its history was monotonous. Trade developed, indeed, but slowly, and the price of iron was little affected save by questions of supply and demand. There is no reason to think that a law—according to experience immutable—will ever be altered, and the future development of the iron trade of the world apparently depends as much as ever on the adoption of inventions startling in their character—little, if at all, on minor improvements in the mere details of manufacture.

The adoption of any new invention, provided it be eminently successful, appears to be invariably followed by two results. The first is that invention for the time is paralysed. Men stand by stunned, and, looking at each other, ask,—"How is it that this was not done before; being done, is there anything left to do?" The secondary result is a revulsion of feeling, and a determination not only to do something but to do something still better. The introduction of the roll train, of the hot blast, and of the steam hammer were each sufficient to stop for the moment all further development of original ideas, but only for the moment. The reaction has only just fairly set in after the pause which followed Mr. Bessemer's splendid innovations on all previous practice, and there is reason to believe that this reaction will be so remarkable, so energetic, and so effectual, that the iron manufacture of Great Britain, if not of the world, will undergo developments more wonderful in their results than any which the trade has yet seen. The most recent innovation is the Radcliffe process, which probably deserves at this moment more attention than any other which has been brought under the notice of the scientific world since Mr. Bessemer astonished the ironmasters of Great Britain by his experiments at Baxter House. Something has been written, and a good deal has been heard in the northern districts about this new process, but little is generally known about it, especially in the southern districts. This want of information we propose to supply, and we write with the full conviction that what we have got to say will be found interesting, and will, perforce, claim attention from every one connected with the manufacture or use of wrought-iron.

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* The Engineer of Feb. 5th and 12th, and April 2nd, 1869.

Nearly a year has elapsed since the Radcliffe process was first brought under our notice. We were told that it consisted, simply stated, in welding two or more puddled balls into a homogeneous mass under the steam hammer. We looked on such a statement with doubt. The welding of puddled balls together in this fashion is not new, and we were perfectly aware that the process had not been attended with good results. The difficulty apparently lay in securing a good weld between the surfaces, exposed as they were to the oxidising influence of the atmosphere. At last evidence reached us which left no room to doubt that something really remarkable had been effected at the Consett Iron Works, near Durham, and we resolved to visit these works and see for ourselves how far the statements made coincided with the truth. What we have seen we shall place here before our readers, leaving them to draw their own conclusions. Before doing so, it will be worth while to detail the ordinary system of producing a finished bar, rail, or sheet. As the Radcliffe process only deals with the conversion of pig-iron into finished bars, rails, or sheets, we need not trace the process further back than the introduction of the pig into the puddling furnace. Four or five hundredweights of pig-iron constitutes a charge, and in converting this into blooms about 22 cwts. of coal are used per ton of finished iron. The quantity varies with the kind of iron produced, the quality of the coal, the skill of the puddler, &c., but the proportion of coal to iron named is not far from the average. The puddled balls, when made, are taken separately to the shingling hammer or squeezer, the cinder is expelled, and the rough bloom is passed through rolls, and puddled bars are produced. These bars are then suffered to cool down till wanted for the next process. In this a given weight of puddled bar is cut into lengths of 18 inches to 3 feet, and several of these lengths—from two to six or eight in number are made into a pile. Several such piles are placed in a heating furnace and raised to a welding heat. They are then withdrawn, one after the other, and rolled off into bars or rails as quickly as possible. Where a very high quality of rail is required the puddled bar bloom is rolled into bars, which are again cut up, piled, re-heated, and rolled into the rail. The best plates are always thus produced, and in manufacturing superlatively good merchant bars the process of cutting, piling, and re-heating is repeated a third time. The cutting and piling of puddled bars will cost about 2s. per ton, and at least 10 cwts. of coal per ton of iron will be required for each re-heating. The finished iron—if the pig be good, and all the processes carefully carried out—will stand a tensile strain of about 22 tons per inch, with an elongation of 15 per cent. The fracture will be fibrous, and the material soft and very malleable. The least consumption of coal to produce one ton of such iron will be one ton for puddling and another for two re-heatings. Every time the iron is put into the furnace it suffers loss by oxidation.

It is very difficult to state exactly what this loss will be, but it cannot be less than 5 per cent or 6 per cent of the weight of the pile, and besides this there will be a loss of from 10 per cent to 20 per cent accounted for by crop ends—roughly stated, 10 per cent of iron is practically wasted at each re-heating. Our readers will do well to bear these facts in mind, as their full realisation is essential to the comprehension of the character and advantages of the Radcliffe process, which in effect does away with all piling, cutting, and re-heating, giving the finished bar rail, or sheet direct from the puddled ball. The immediate advantages are—firstly, a saving of at least 1 ton of coal per ton of finished material; secondly, a saving in time of great importance; thirdly, a saving in iron; fourthly, a saving in labour; and, fifthly, a gain in quality, depending on some phenomena attending the process of manufacture to which we shall have occasion to refer more fully hereafter. Our business is, first, to record facts; secondly, as far as possible, to explain them.

As Consett Works are little known out of the north, and as it is well that our readers should understand that the Radcliffe process is not an experiment, but a commercial reality—hundreds, if not thousands, of tons of iron being now made by it—it will be well to digress here, and give a general description of the works, which present many noteworthy features.

The Consett Ironworks are situated about twenty miles from Durham, and less than one mile from Benfieldside station on the Durham and Consett line. There are in work four blast furnaces. About 200,000 tons of ore are converted into pig-iron each year. There are three blast engines, two double* and two single mills under one roof, and three single mills under another. Each double mill can turn out about 450 tons of plates per week, and as many as

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* The double mills are so called, not because of any peculiarity of construction, but because, from their large dimensions and great power, they can utilise nearly double as many furnaces as the smaller or single mills. The rolls of the double mills are 26 inches in diameter, and of the single mills 24 inches in diameter.

1300 tons of plates per week have been made when all the mills were at work. In addition, there is a very fine rail mill competent to make 800 to 1000 tons of rails per week. Besides these there are three puddling trains, 160 puddling furnaces, and 48 heating furnaces of all kinds. The company possess, besides, ten locomotives, and they employ between the works and their colliery about 6000 hands. It will be allowed, we think, that a process worked with commercial success at such an establishment as this deserves no common amount of attention.

On the 30th of January, 1868, Mr. James Radcliffe, general manager of the Consett Ironworks, patented the process now known by his name. The patent is numbered 321, and we cannot better describe the principle of the process than by using Mr. Radcliffe's own words, quoted from his specification :—

"I first combine into one homogeneous mass, of suitable form and weight to form the required shape and weight when finished, five or any larger number of ordinary puddled balls of iron or steel, each of which usually weighs about 1 cwt., or an equivalent weight of puddled iron or steel may be taken direct from the puddling furnace sufficient to form a mass of metal of the required shape and weight when finished by means of a powerful steam hammer, or other mechanical equivalent of suitable power or dimensions, or by means of pressure suitably applied. For this purpose, in carrying out my improvements, the puddled balls of iron or steel (or an equivalent weight of puddled iron or steel in one mass) are conveyed from the puddling furnace or furnaces to the working, pressing, or combining apparatus, which may be variously constructed and arranged, but which I prefer to be a powerful steam hammer so proportioned, arranged, and worked by high pressure steam that the hammer can be quickly raised and caused to descend rapidly by means of the pressure of steam on the upper side of the piston. By this means the puddled balls of iron as they are accumulated upon the anvil from the puddling furnaces (or an equivalent weight of puddled iron in one mass) are directly operated upon and quickly consolidated and combined into a mass by a series of powerful and rapid blows, and after a sufficient mass of puddled iron is accumulated and dealt with in this way is turned "upset" and worked under the hammer on all sides until it is formed into one homogeneous "slab" or "bloom" of suitable form for the subsequent process; and I will here remark that it is advisable to employ a hammer 10 tons in weight for dealing with an accumulated mass of ten ordinary puddled balls or an equivalent weight (say, 1100 lbs.) of puddled iron or steel according to my improvements, and a hammer of 20 tons in weight should be employed for dealing with an accumulated mass of twenty ordinary puddled balls, or an equivalent weight of puddled iron, and so on in proportion."

In practice this process differs in one remarkable particular from others intended to fulfil the same object in the same way. It has hitherto been the aim of ironmakers when welding two or more puddled balls together to bring out the iron old or well worked, and in this fact lies, in all probability, the failure of Mr. Radcliffe's predecessors. The bloom, under the hammer, quickly assumed a condition approaching to that of wrought-iron; the mass became indurated, the surface was oxidised, and great difficulty was encountered in securing sound welds. Mr. Bramwell's criticisms on the process, already referred to in our pages, were justified by his supposition that Mr. Radcliffe's process was identical with the attempts of others in this direction. In order to understand the true theory of the process, and to comprehend what actually takes place, it is absolutely necessary to see the thing carried out, and it will then be perceived that with ordinary care it is impossible to produce anything but a homogeneous mass.

The details of the process as carried out at Consett may thus be described. Six, eight, or any required number of puddling furnaces are each charged with four cwts. of pig-iron. The fettling consists partly of pulverised hæmatite ore from Ulverstone, partly of a very rich cinder obtained from the first pile-heating furnaces in the rail mill, or from two furnaces specially employed in making cinder from small scrap. The iron is brought to nature as soon as possible, and the blooms are taken out while the iron is yet very young—as soon, indeed, as the balls will hold together. The moment the iron is ready in a sufficient number of furnaces, the process of manufacture begins. A puddler takes a ball weighing about 80 lbs. to an 8-ton double-acting steam hammer. It is placed on the anvil and struck, first lightly, and then, as the mass becomes consolidated, with more force. The cinder is expelled with considerable violence, and we have, at the end of twenty seconds, a flat cake of iron on the anvil perfectly quiescent. At this moment a second puddled ball is placed on the first. This receives, first a light, and then a couple of heavy blows. The hammer is raised for a few seconds, and then a curious action takes place. The first and second blows apparently expelled most of the cinder, and the mass, seemingly, tolerably solid, lies quietly on the anvil, but in a moment its surface rises like a cake of dough in a baker's oven. The surface seems to boil; little jets of flame sometimes start from the mass, and cinder pours in a torrent from every pore, flowing over the lump of iron, and running down all round. To what this peculiar action is due we cannot say. That this, in a sense, spontaneous evolution of cinder is a fact we can testify from close personal observation. A few blows from the steam hammer again consolidate the heaving mass. Another ball is placed on it; a few blows; a short pause. The rising of the mass and the flow of torrents of cinder follow as quickly as thought, and so the process is continued till eight balls are united. Then steam is brought to bear on the upper side of the hammer piston. The mass of iron is turned and re-turned, while the whole shop resounds with the sound of the hammer delivering blows with the speed of lightning on every portion of the red-hot mass, which finally assumes the form of a homogeneous slab some 3 feet long, 13 inches or 14 inches wide, and 8 inches or 9 inches thick. This slab is then taken up by a little steam crane at the side of the hammer, and, while hanging in the air, weighed. It is then run off to a heating furnace preparatory to being rolled into a finished plate. The heating furnace is of the ordinary kind, and is only used to restore the heat lost by the outer surface of the mass. From the furnace it is taken to the roll mill, passed through the breaking-down grain rolls, and subsequently between a pair of chilled rolls in the same train, and, finally, it lies on the floor of the shop, a plate with whose appearance the most hypercritical can find no fault.

Mr. Radcliffe courts inquiry, and we were afforded the fullest possible opportunities for examining into the process known by his name. We witnessed the formation of many plates, and the following particulars of the manufacture of one, selected almost haphazard from our note-book, will show nearly at a glance of what the process is capable.

At half-past three p.m. the first of eight puddled balls was brought from the furnace and placed on the anvil. In four minutes and a half this and seven other balls were welded into a slab weighing 584 lbs. At twenty-six minutes to four o'clock this pile was placed in the heating furnace; at nineteen minutes to four o'clock it was taken out and brought to the rolls; at fourteen minutes to four o'clock it lay on the floor of the mill ready for shearing. Thus precisely sixteen minutes were occupied in producing the plate from the puddled ball. The weight of the plate before shearing was 574 lbs. It was then sheared to the finished size, 20 feet by 3 feet; thickness, 3-16th inch nearly; weight sheared, 448 lbs. Is it necessary to point out here how much is gained in time, coal, iron, labour, and, finally, in money, by the Radcliffe process as compared with old systems of manufacture? We think that they will be apparent at a glance to every ironmaster. What we have said in the beginning of this article should suffice to make them clear to others.

The question that here obtrudes itself is, what is the quality of the finished plate, bar, or rail? Unless the answer is satisfactory, the Radcliffe process—ingenious, cheap, and rapid as it is—is comparatively valueless. At Consett we examined some scores of specimens of sheets tested in every possible way. Plates ⅞th inch thick bent cold to an angle of 90°, thinner plates bent up on themselves, coiled into a helix, split and bent backwards and forwards, dished up into troughs, twisted and tortured in every imaginable fashion punched close to the edge—as close as holes would go—yet no symptoms of crack or flaw. We have no hesitation in classing the specimens we examined with the very best ship-plates in the market; and yet these plates are produced at a price which has enabled Mr. Radcliffe to take very heavy orders from Dutch shipbuilders, beating Belgium out of the market, and yet leaving a fair profit. We give here a copy of a certificate from Mr. Kirkaldy, referring to some specimens of plates tested as far back as February, 1868. It will be objected that the extension of some of the samples is small. We wish our readers to bear in mind that the pig-iron from which the sheets tested were made cost just 40s. per ton; they can then draw their own conclusions.

RESULTS OF EXPERIMENTS TO ASCERTAIN THE TENSILE STRENGTH, ETC., OF FIVE PIECES OF IRON PLATE, EDGES PLANED, RECEIVED READY FOR TESTING FROM MESSRS. THE CONSETT IRON COMPANY.

| Original. | | Ultimate stress. | | | | Fractured. | | | | Stress per sq. in. of fractured area. | Extension. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size. | Area. | Total. | Per square inch of original area. | | | Size. | Area. | Difference. Per cent. | | | Per cent. | |
| | | | | | tons. | | | | | | | |
| 2·29×0·37 | 0·847 | 51,710 | 61,050 | 57,583 | 27¼ | 2·17×0·30 | 0·651 | 23·5 | 17·7 | | 13·3 | 9·2 |
| 2·29×0·37 | 0·847 | 51,820 | 61,180 | | 27·6 | 2·16×0·32 | 0·691 | 18·4 | | | 9·1 | |
| 2·28×0·20 | 0·456 | 26,705 | 58,563 | | 26 | 2·13×0·17 | 0·362 | 20·6 | | | 11·3 | |
| 2·28×0·20 | 0·456 | 26,050 | 57,127 | | 25½ | 2·17×0·17 | 0·369 | 19·1 | | 71,777 | 9·2 | |
| 2·28×0·20 | 0·456 | 22,798 | 49,995 | | 22 | 2·23×0·19 | 0·424 | 00·0 | | | 3·1 | |

DAVID KIRKALDY.

Messrs. THE CONSETT IRON COMPANY,
JASPER C. MAUNSEY, Esq., 118, Cannon Street, E.C.
The Grove, Southwark Street, S.E., 22nd February, 1868.

As further confirmation of the good opinion we have formed of the iron produced by the Radcliffe process, we may add that we have testimonials lying before us from one of the largest shipbuilding firms in Newcastle-on-Tyne, expressing the most unqualified approval of sheets manufactured by the Radcliffe process.

We have said enough, we think, to make our readers familiar with the nature of the new system of manufacture, but much remains to be said as regards the nature and peculiarities of the finished production, which, in a sense, deserves to rank as a new material.

We append a record of some experiments made recently by Mr. Kirkaldy, which speak for themselves. In one case a sample, it will be seen, stood 32 tons, and stretched 22 per cent; in another the extreme was 30 per cent, and the breaking stress 27 tons. These results are almost unparalleled and commend the process to every engineer and boiler maker in the kingdom.

Results of Experiments to Ascertain the Tensile Strength, etc., of Twenty-four Pieces of Iron Plate Received from Messrs. The Consett Iron Company.

| | Original. | | Ultimate Stress. | | | | Fracture. | | Extension. |
|---|---|---|---|---|---|---|---|---|---|
| Description. | Size. | Area. | Total. | Per Square Inch of Original Area. | | | Area. | Difference. | |
| | | | | | lbs. | tons. | | p. c. | p. c. |
| ⅜ plate length | 1·94 × 0·37 | 0·718 | 52,840 | 73,593 | 72,039 | 32·2 | 0·579 | 22·1 | 13·1 |
| " | 1·97 × 0·37 | 0·729 | 52,155 | 71,543 | | | 0·574 | | |
| " | 1·98 × 0·37 | 0·732 | 51,960 | 70,983 | | | 0·536 | | |
| × cross | 1·96 × 0·37 | 0·725 | 46,660 | 64,358 | 63,223 | 28·2 | 0·639 | 8·4 | 5·4 |
| × " | 1·94 × 0·36 | 0·698 | 43,945 | 62,958 | | | 0·654 | | |
| × " | 1·94 × 0·37 | 0·718 | 44,770 | 62,353 | | | 0·668 | | |
| ⅛ plate length | 1·77 × 0·14 | 0·248 | 17,445 | 70,342 | | | 0·186 | | |
| " | 1·78 × 0·14 | 0·249 | 16,905 | 67,891 | 60,521 | 27·5 | 0·189 | 30·0 | 11·3 |
| " | 1·77 × 0·14 | 0·248 | 16,605 | 66,955 | | | 0·173 | | |
| " | 1·78 × 0·14 | 0·249 | 16,180 | 64,980 | | | 0·138 | | |
| " | 1·77 × 0·14 | 0·248 | 15,195 | 61,770 | | | 0·174 | | |
| " | 1·77 × 0·14 | 0·248 | 14,842 | 55,846 | | | 0·177 | | |
| " | 1·77 × 0·15 | 0·265 | 15,082 | 56,913 | | | 0·163 | | |
| " | 1·78 × 0·14 | 0·249 | 13,705 | 55,040 | | | 0·159 | | |
| " | 1·77 × 0·14 | 0·248 | 12,512 | 50,451 | | | 0·185 | | |
| × cross | 1·78 × 0·15 | 0·267 | 18,030 | 67,528 | 56,163 | 26·4 | 0·221 | 12·7 | 5·8 |
| × " | 1·78 × 0·16 | 0·285 | 18,374 | 64,470 | | | 0·235 | | |
| × " | 1·78 × 0·14 | 0·249 | 15,075 | 60,542 | | | 0·222 | | |
| × " | 1·78 × 0·14 | 0·249 | 14,854 | 54,775 | | | 0·226 | | |
| × " | 1·78 × 0·16 | 0·283 | 16,864 | 59,590 | | | 0·256 | | |
| × " | 1·78 × 0·14 | 0·249 | 14,422 | 57,920 | | | 0·226 | | |
| × " | 1·78 × 0·16 | 0·285 | 16,494 | 57,873 | | | 0·239 | | |
| × " | 1·78 × 0·16 | 0·285 | 15,116 | 53,038 | | | 0·261 | | |
| × " | 1·78 × 0·14 | 0·249 | 12,856 | 51,630 | | | 0·286 | | |

The fracture of the plates was fibrous, light grey.

The above were tested as received, and without being heated and annealed. (Signed) David Kirkaldy.

## THE ELLERSHAUSEN PROCESS.*

The recent invention of Mr. Ellershausen, which is now regularly in use in Pittsburgh, Pa., and is being rapidly introduced all over the country, has greatly advanced the solution of the problem of the cheap iron.

The process consists in the conversion of crude cast-iron, as it runs from the smelting furnace, into wrought-iron, by the simple admixture of pulverised iron ore. It is carried out at the works of Messrs. Shoenberger, at Pittsburg, in the following manner:—On the casting floor of the smelting furnace, a cast-iron turn-table, about 18 feet diameter, is revolved on rollers by a small steam engine. Upon the outside edge of the table stand a row of cast-iron partitions, forming boxes, say 20 inches wide and 10 inches high, open at the top. Just above the circle of boxes stands a stationary, wide-mouthed spout, terminating in the tap-hole of the furnace. When the furnace is tapped, the liquid iron runs down this spout, and falls out of it in a thin stream into the boxes as they slowly revolve under it, depositing in each a film of iron say one-eighth of an inch thick. But before the fall of melted iron reaches the boxes it is intercepted, or rather crossed, at right angles, by a thin fall of pulverised iron ore, which also runs out of a wide spout from a reservoir above. These two streams or falls are of about equal volume, say ¼ of an inch deep and 20 inches wide. A workman, with a bar in the tap-hole, regulates the stream of iron, and the iron spout from which the liquid metal falls into the boxes is removable; other spouts, previously coated with loam and dried, being attached to a common revolving frame, so as to be ready for use when the loam covering of the first becomes cracked or removed.

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* Chemical News, vol. xix., p. 230.

The thin layers of iron and ore soon chill and solidify, so that by taking away the outer partition of the boxes (which form the rim of the turn-table) they may be removed in cakes of the size of the boxes and weighing about 200 lbs. each. Four of these cakes or blooms are put into a reverberatory puddling or heating furnace, and raised to a bright yellow heat. They will not melt at this heat, but becomes softened so as to be easily broken up with a bar. The four blooms are formed in the furnace by the "rabble" of the workmen, as in ordinary puddling operations, into eight balls. The balls are brought out one after another, squeezed in the ordinary "squeezers" to expel the cinder and superfluous ore, and then rolled into wrought-iron bars, which are now ready for market, or for further reduction into smaller finished forms.

The chemistry of the operation is as follows:—The crude cast-iron contains, say, 5 per cent of carbon, and 2 per cent of silicon, and more or less sulphur, phosphorus, and other impurities. In the Bessemer process the oxygen of the air, blown into the liquid iron, combines with this carbon and these other impurities, and not only removes them [?] but leaves the pure iron in a liquid state, from which it can be cast into homogeneous masses of any size. In the puddling process, the oxygen of the air and of the ore or other "fettling" put into the furnace with the iron combines with and eliminates the impurities, which are afterwards squeezed out of the pasty mass by the squeezers and rolls. This process is long and comparatively expensive, because the mixture of oxygen or oxygen-bearing substances is not made intimate with the iron except by long stirring, which is not only skilful but exhausting work.

In the Ellershausen process the oxygen of the ore of oxide of iron (manganesic oxide is preferred) combines with the carbon and impurities, eliminating them as in the puddling process, and the iron of the ore increases the product. The chemical combination of the ore and the liquid crude iron appears to take place partly at the time of their contact when falling and lying upon the turn-table, and partly where the re-heating occurs in the furnace. It seems impossible that a reaction which is so violent in the Bessemer process, and so prolonged in puddling, should take place so quickly and quietly in the new process, but the fact that the cakes of iron and ore do not melt by subsequent heating, as cast-iron would, proves that its nature is changed by the first contact of the ore. The removal of sulphur and of phosphorus also seems more thorough than in the other processes. Analyses at different stages of the operation will throw more light on this question.

The remarkable feature of the Ellershausen process is that absolutely no skill is required to carry it out. The proportion of ore mixed is intended to be about 30 per cent, but if too much is added, it is readily squeezed out with the slag, and seems to do no harm. The subsequent heating occupies about half an hour. "Puddle-bar," the product obtained from the first rolling of the product of the puddling furnace, is never marketable or finished iron. It is usually very ragged and unsound, and requires subsequent piling, re-heating, and re-rolling, to expel the impurities, and to give it soundness and solidity. The new process appears to produce merchantable iron at the first rolling, and at Pittsburg, from a very inferior pig-iron made of one half sulphurous Canada ores, and one quarter Lake Superior and one quarter Iron Mountain ores.

The thoroughness and rapidity of the purification by this process evidently depend on the intimacy of the mixture of iron and ore. This intimate mixture is also the essence of the Bessemer process. In fact, to Mr. Bessemer's original apprehension of this idea of intimate mechanical mixture the greatest modern improvements in the iron manufacture are due.

The Ellershausen process is said to decrease the cost of wrought-iron from 10 dollars to 20 or 30 dollars per ton, according to the materials used and the form of the product required. That it is a success is amply proved by regular working at Pittsburg and many experiments elsewhere.

The Sharon, Pa., *Herald*, of the 28th ult., contains the following account of a test of the Ellershausen process for puddling iron.*

This new process of manufacturing iron directly from the ore was tested yesterday, with success, at furnace No. 1, of the Westerman Iron Company. The process consists in the conversion of crude metal, as it runs from the furnace, into wrought-iron. At the furnace of the Westerman Iron Company, preparations for trying this new process were made by excavating the floor of one side of the casting house to the depth of 3 feet and about 20 feet wide by 30 feet long. Upon the floor of this excavation were placed a cast-iron turn-table and an engine of thirty horse-power; the latter for turning the table and for hoisting the pulverised ore, which is mixed with the metal, in a reservoir over the turn-table. Upon the rim of the table is a row of cast-iron boxes, about 10 inches wide, 20 inches long, and 12 inches deep, with the sides and outside end movable, the latter held in place by clamps. Directly over the boxes is a wide-mouthed spout, and over that, one end of the runner, the other terminating at the notch in the furnace. Boxes, spout, and runner are all well covered with loam, and dried before using. When the furnace is tapped, the liquid metal follows the runner to the end, falls into the wide spout, and thence in a broad, shallow stream into the boxes below; the latter having their bottoms covered with ½ an inch of pulverised Champlain ore, and being slowly revolved by the engine. As soon as the boxes pass from under the spout by which the metal is let into them, the metal in them is covered with a thin covering of pulverised iron ore, which runs in a thin stream through a broad spout leading from the reservoir before spoken of. In the casting which we witnessed yesterday evening, about 5 tons were run into the boxes, and the table revolved nine or ten times. As the layers of metal and ore are necessarily thin, from passing alternately under the spouts mentioned above, they soon chill, and then are easily removed by taking off the clamps holding the ends in place, and then removing the ends. These cakes—the size of the boxes—weigh from 150 to 250 lbs. each, and are about as easily handled as the ordinary pigs cast in chills.

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* American Journal of Mining, June 19, 1869.

We understand that the necessary machinery and changes for manufacturing iron by this new process cost the company about 7000 dollars, and that, as soon as practicable, the same process will be applied to furnace No. 2. The advantages claimed by this process are that, no matter what kind of metal the furnace produces, the mixing of ore with it makes it good iron; that, as it is made into iron when casting, it needs no puddling; and, that it produces much better iron than the old way. It has been calculated by some that the same amount of ore, coal, labour, &c., will produce 30 per cent more iron and of a better quality than the old way.

## BLAST FURNACE ECONOMY.*

At the meeting of the Institution of Mechanical Engineers, held on the 28th of January last, during the discussion which took place on Mr. Cochrane's paper on the utilisation of waste gases from blast furnaces, attention was especially directed to the differences which exist between the quantities of fuel actually consumed in blast furnaces per ton of iron produced and the amounts which would be theoretically required; and the subject is altogether one of such importance as to deserve especial consideration. And here we may remark that it is quite impossible, in the present state of our metallurgical knowledge, to say precisely how much fuel is absolutely wasted in any given blast furnace. The quantities of fuel, ore, and fluxes introduced in any given time, and their analyses, may be accurately known to us; but our information concerning the quantities of heat rendered latent in destroying certain chemical combinations, the heat absorbed in liquefying the slag and the iron itself; the specific heat of the liquid slag and iron, and other matters, is far from being so reliable as we could wish, and, consequently, as we have said, a thoroughly accurate estimate of the fuel required in any given instance cannot at present be given. Notwithstanding this, however, we have sufficient data at our disposal to show that the amount of fuel actually used is greater than it should be, and it may be interesting if we consider this matter more closely. For this purpose it will be convenient if we take, as an example, a furnace worked with certain definite charges of ore and fuel, and show how the proportions between those charges agree with those which would be theoretically required.

Let us, for instance, consider a furnace in which the charges consist of 26 cwts. of coke, 50 cwts. of ironstone, and 10 cwts. of limestone per ton of iron run; the ironstone containing 40 per cent of iron in the state of peroxide. We have chosen these proportions because they will enable us to readily compare our calculations with those of Mr. I. Lowthian Bell and Mr. Siemens, given in the course of the discussion to which we have already referred, and which were founded on similar data. In the first place, the coke used in the Cleveland district contains from 5 to 10 per cent of ash and moisture, and if we assume that our particular sample contains 7½ per cent of these matters, we shall have to make a deduction of 1½ cwts. from the quantity available as fuel. A further deduction of about 1 cwt. will have to be made for the carbon which combines with the iron, leaving, finally, 23½ cwts. of carbon to be accounted for.

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* Engineering, April 30, 1869.

Peroxide of iron, ($Fe_2O_3$), consists of 56 parts by weight of iron combined with 24 of oxygen, and the 50 cwts. of ironstone charged per ton of iron made contain, therefore, 20 cwts. of iron, 8·57 cwts. of oxygen, and 21·43 cwts. of other materials, principally silica. The decomposition of the peroxide is effected by its oxygen being taken up by the carbonic oxide gas produced by the imperfect combustion of the coke, this carbonic oxide being thus converted into carbonic acid. The amount of carbonic oxide required to decompose the given quantity of peroxide of iron is readily calculated. Carbonic oxide consisting of 6 parts by weight of carbon combined with 8 parts of oxygen, and carbonic acid consisting of 6 parts of carbon and 16 of oxygen, it follows that to take up the 8·57 cwts. of oxygen from the peroxide of iron, 15 cwts. of carbonic oxide (composed of 6·43 cwts. of carbon and 8·57 cwts. of oxygen) will be necessary. This disposes of 6·43 cwts. out of the 23½ cwts. of carbon. But in converting the oxygen of the peroxide from the solid to the gaseous form there is a great absorption of heat, and to supply this heat a consumption of fuel has to take place. It appears from the researches of Ebelmen and Schinz that the quantity of heat rendered latent during the decomposition of the peroxide of iron amounts to 718 units for each pound of oxide decomposed, and as in our example the quantity of peroxide is 28·57 cwts., the heat absorbed would be $28{\cdot}57 \times 112 \times 718 = 229{,}748{,}512$ units. We must next consider the quantity of fuel required to supply this amount of heat.

If the whole of the carbon consumed in a blast furnace was converted into carbonic acid, each pound of it would develope about 14,000 units of heat; but, as a fact, it appears probable that, as estimated by Mr. Siemens, not more than one-fifth is thus converted, the remaining four-fifths assuming the form of carbonic oxide. As carbon, when burnt into carbonic oxide, only produces about 4000 units of heat, we thus have, as the average quantity of heat produced by each pound of carbon consumed in the furnace (1-5th × 14,000) + (4-5ths + 4000) = 6000 units, and this we believe is a fair estimate. From these data we get $\frac{229,748,512}{6000 \times 112} = 3·418$, or, say, 3·42 cwts. as the quantity of fuel required to supply the heat rendered latent during the decomposition of the peroxide of iron. We have next to consider the amount of heat rendered latent during the decomposition of the limestone; and, according to the experiments of Schinz, this amounts to 355 units for each pound of carbonate of lime decomposed. In our case, therefore, the quantity will be $10 \times 112 \times 355 = 397,600$ units corresponding to the consumption of $\frac{397,600}{6000 \times 112} = 0·591$, or, say, 0·6 cwt. of fuel.

At the time that the iron and slag are discharged from a blast furnace they have a temperature which may be fairly assumed as about 2400 degrees higher than that of the materials at the time of charging, and we have now to consider the amount of heat necessary to liquefy them and give them this high temperature. The amount of heat rendered latent during the liquefaction of a pound of cast-iron has been given by Clement as 233 units, and by Schinz as varying in different samples from 250 to 315 units. If we assume 250 units as the amount in the present case, we shall have $250 \times 20 \times 112 = 560,000$ units as the amount rendered latent during the liquefaction of the ton of iron. Again, the specific heat of cast-iron in the solid state is 0·13, and in the liquid state about 0·16; and we shall, therefore, have $20 \times 112 \times 0·13 \times 2000 = 582,400$ units of heat absorbed in raising the ton of iron to the melting point, and $20 \times 112 \times 0·16 \times 400 = 143,360$ units imparted to it after it is melted. Adding these quantities together, we get $560,000 + 582,400 + 143,360 = 1,285,760$ units, thus corresponding to the consumption of $\frac{1,285,760}{6000 \times 112} = 1·91$ cwts. of fuel.

As to the quantity of heat rendered latent during the liquefaction of the slag, some little uncertainty exists, and it, moreover, no doubt varies in slags of different compositions. The researches of various continental experimenters, however, tend to show that 110 units per pound of slag melted may be taken as a fair estimate in ordinary cases. With the charges mentioned in our example, the quantity of slag produced would be about 29½ or 30 cwts. per ton of iron made, and taking the latter quantity, we should have $30 \times 112 \times 110 = 369{,}600$ units. The specific heat of slag, like that of iron, varies according to whether the material is in the solid or liquid form; but we may, without any serious error, assume it as being 0·2 throughout. The quantity of heat required to raise the temperature of the materials forming the slag about 2400° will thus be $2400 \times 30 \times 112 \times 0{\cdot}2 = 1{,}612{,}800$ units; and adding to this the 369,600 units absorbed during liquefaction, we get 1,982,400 units as the total heat imparted to the slag, this corresponding to the consumption of $\frac{1{,}982{,}40}{6000 \times 112} = 2{\cdot}94$, or, say, 3 cwts. of fuel.

Summarising the results above obtained, we get the following statement of the manner in which the 26 cwts. of fuel is disposed of :—

| | Cwts. |
|---|---|
| Ashes and moisture in fuel . . . . . . | 1·50 |
| Carburisation of the melted iron . . . . | 1·00 |
| Carbon for combining with oxygen in ore . | 6·43 |
| Fuel for melting iron . . . . . . . . . | 1·91 |
| ,, ,, slag . . . . . . . . . | 3·00 |
| ,, to supply heat rendered latent during decomposition of ironstone . . . | 3·42 |
| ,, ditto during decomposition of limestone | 0·60 |
| | 17·86 |
| Not accounted for above . . . . . . . . | 8·14 |
| Total . . . . . . . . . | 26·00 |

In the above summary we have taken no account of the heat carried off by the waste gases escaping at the mouth of the furnace, for we quite agree with Mr. Siemens in considering that this amount is more than balanced by the heat introduced into the furnace by the hot blast, supposing the latter to be heated to, say, 1000°. A simple calculation will prove this. We have shown that of the 26 cwts. of coke 23½ cwts. would be actually consumed as fuel (for the amount which unites with the oxygen of the ore is really consumed), and of this quantity we have assumed one-fifth or 4·7 cwts. to be converted into carbonic acid, and the remainder, or 18·8 cwts. into carbonic oxide. The 4·7 cwts. converted into carbonic acid, would require $\frac{\cdot 7 \times 16}{6} = 12{\cdot}63$ cwts. of oxygen for their conversion, whilst the remaining 18·8 cwts. would combine with $\frac{18{\cdot}8 \times 8}{6} = 25{\cdot}06$ cwts. of oxygen in forming carbonic oxide. The total quantity of oxygen required for chemical combination alone would thus be $12{\cdot}63 + 25{\cdot}06 = 37{\cdot}69$ cwts., and of this quantity 8·57 cwts. would be supplied by the iron ore, leaving 29·12, or, say, 29 cwts. to be provided by the blast. Taking the air as being composed of 22 per cent by weight of oxygen, 77 per cent of nitrogen, and 1 per cent of moisture, carbonic acid, &c., we have $\frac{29 \times 100}{22} = 131{\cdot}7$, or, say, 132 cwts. of blast as the amount necessary to furnish the above supply of oxygen. The specific heat of air being 0·238, this quantity of blast, if heated 1000° above the ordinary atmospheric temperature, will thus introduce into the furnace $1000 \times 0{\cdot}238 \times 132 \times 112 = 3{,}518{,}592$ units of heat.

On the other hand, the gases escaping from the mouth of the furnace consist of 4·4 cwts. of carbonic acid derived from the limestone, 8·57 cwts. of oxygen from the peroxide of iron, 132 cwts. of oxygen, nitrogen, &c., from the blast, and 23·5 cwts. of carbon, combined with the oxygen of the air and that from the peroxide of iron, in the form of carbonic acid and carbonic oxide. The total weight of the gases will thus be $4{\cdot}4 + 8{\cdot}57 + 132 + 22{\cdot}5 = 168{\cdot}47$, or, say, 168½ cwts. Taking the specific heat of these mixed gases to be 0·24, and their temperature to be 600°, we shall thus have $169{\cdot}5 \times 112 \times 0{\cdot}24 \times 600 = 2{,}717{,}568$ units of heat carried off by them, this quantity being $3{,}518{,}592 - 2{,}717{,}568 = 801{,}024$ units less than is introduced by the blast. To some extent this overplus would no doubt be reduced by the heat carried off by radiation from the pipes by the water circulating through the tuyeres, &c., but we think there can be little doubt that the heat introduced by the hot blast will fully compensate for that carried off by the waste gases.

It may be interesting if we compare our calculations as to the disposal of the fuel above given with the estimates given by Mr. I. Lowthian Bell and Mr. Siemens on the occasion of the discussion to which we have already referred. Mr. Bell's estimate was as follows:—

| | Cwts. |
|---|---|
| Carbonisation of the melted iron | 1·00 |
| Melting the iron, and keeping it melted on the hearth | 2·70 |
| Ditto as regards the cinder | 4·50 |
| Heat carried off by the escaping gases | 6·36 |
| Heat rendered latent, including the 6·43 cwts. of carbon combining with the oxygen in the ore, say, altogether | 9·00 |
| Total | 23·56 |

It will be noticed that in the above estimate, although Mr. Bell allows 6·36 cwts. as the equivalent of fuel carried off by the waste gases, he makes no allowance for the heat introduced by the blast. Assuming, as we have done, that these two quantities balance each other, and deducting from Mr. Bell's estimate the 6·36 cwts. just mentioned, we get, as a remainder, 17·2 cwts., a quantity closely agreeing with that shown by our own calculations. Mr. Siemens's estimate, which also agrees closely with our own, was as follows:—

| | Cwts. | |
|---|---|---|
| Melting the iron | 1·60 | |
| Melting the cinder | 4·13 | |
| Heat rendered latent by reduction of ore | 3·19 | |
| Carbon for combining with oxygen in ore and for carbonising pig metal | 7·43 | |
| | | 16·35 |
| Ashes and water in coke, 10 per cent | | 1·63 |
| Calcining the limestone, &c., 10 per cent | | 1·63 |
| Total quantity of coke required | | 19·61 |

Of the 8·14 cwts. of coke per ton of iron, given in our own estimate as unaccounted for by the useful work done, a portion is no doubt expended in supplying the heat lost by radiation from the furnace, but we have no reliable data which will enable us to estimate what the amount of this loss will be. There is, however, little cause for supposing that it is sufficient to account for the heat generated by the combustion of about one-third of the total quantity of fuel, and there must therefore be some other sources of waste not sufficiently recognised, but which it is desirable should be sought after, and, if possible, avoided.

## IRON AND STEEL.*

J. A. Jones, Middlesborough.—Patent dated February 5, 1868.

This invention relates to certain improvements in the production of iron and steel from cast- or pig-iron, and consists in melting cast- or pig-iron in a reverberatory or other melting furnace, and, after fusion, agitating the same, and then having by preference lowered the damper of the furnace, adding to the melted metal a flux consisting of oxide of manganese, common salt, sal-ammoniac, or any of them together with spiegeleisen. After agitation, and when the ingredients before-mentioned shall have been incorporated with the molten metal, the damper is to be raised, and the charge or contents of the furnace are again rendered fluid, so as to enable the separation of the cinder or slag from the resulting metal to be effected. The cinder is then tapped and run off, and the crude iron or metal is removed from the furnace and melted into steel, either on the open hearth of a furnace or in a crucible. The puddling furnace preferred to be employed may be similar to those at present in use, or it may be specially constructed so as to produce a larger quantity of material, or it may be constructed of such other form as may be well adapted for the successful carrying out of my improved process.

It is preferred to fettle the sides and bridge of the furnace with oxides of iron, such as hæmatite ore, Swedish ironstone, or mill tap cinder, which materially assist in effecting the cleansing of the iron from certain impurities, such, for example, as sulphur and phosphorus, which impurities, as is well known, are injurious to the quality of iron or steel to be produced. Slag, and by preference that known as hammer slag, is placed among the pig- or cast-iron in order, when melted, to form a bath in which the iron may be washed. This is not absolutely necessary, but it materially assists in effecting the purification of the iron. The pig- or cast-iron, together with the slag, is placed in a furnace and is therein melted, and after having been well puddled, agitated, or stirred, the damper of the furnace is closed; or, in place of the pig- or cast-iron being melted in the puddling or operating furnace, it may be melted in a cupola, or air, or other furnace, and thence run into the puddling furnace to be operated upon, thus saving time and fuel. When the damper has been lowered, as before described, to the mass is added, in either case, a mixture comprised of the following ingredients: viz., oxide of manganese, common salt, sal-ammoniac, spiegeleisen, and ground charcoal.

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* The Practical Mechanic's Journal, Nov. 1, 1868.

The proportions which have been found to give good results are, to a charge of 4½ cwts. of pig- or cast-iron, about—

1½ lbs. of manganese.
4 ,, ,, common salt.
¼ lb. of sal-ammoniac.
¼ cwt. of spiegeleisen.
½ lb. of charcoal.

In addition to these, iron ore, such as hæmatite, may be added, either in lumps, or ground small or fine. About 50 lbs. to the charge of 4½ cwts. of pig- or cast-iron is found advantageous. These proportions may be varied, and any of the ingredients may be omitted if desired. The molten iron, together with the flux or fluxes which have been added thereto, is now agitated, stirred, or again puddled, after which operation the damper may be raised and more heat applied, until the cinder becomes more liquid, and the grains of crude iron have aggregated and have settled to the bottom of the furnace. The cinder or slag may then be tapped off from the crude iron or metal, and the latter may be removed from the furnace and may be plunged hot into water. Previous to the crude iron being plunged into water, it may be pressed, tilted, or hammered, so that a portion of its cinder may be removed. It may sometimes not be absolutely necessary to flux all kinds of pigs or cast-iron as described, nor to line or fettle the furnace with oxides of iron, but such a flux or fluxes as described, together with oxides of iron, tend to purify the iron or metal, and to render it more suitable for subsequent melting into steel. The crude iron or metal resulting, as before described, having been removed from the operating furnace, and, if required, submitted to pressure or hammered, so as to remove a portion of its cinder, and then plunged into water, is now to be gradually heated to a red or white heat, and placed by degrees in the open hearth of a steel-melting furnace, such, for example, as Siemens's furnace, as at present constructed for melting steel on the open hearth, or on the hearth, or in crucibles placed in other furnace or furnaces capable of melting the same into steel.

A small quantity of cinder is placed on the hearth of the steel-melting furnace, which may be made from sand, lime, and salt melted together, or blast-furnace slag may be used. This will act as a protective covering to the iron or steel, as well as forming a bath into which the first few loads or charges of the crude iron or metal is placed, or the bath may be composed of cast-iron alone, or in conjunction with the slag or cinder. This cinder, or a portion of it, may, as the charging of the furnace continues, be allowed to run off the steel, or if there be so much as to incommode the working of the furnace, it may be tapped away.

When the crude iron or metal is melted, the quality and temper of the product can be ascertained by taking out a portion from time to time and testing it by smithing, or otherwise, as is well understood. If the steel be found too soft, cast-iron may be added to harden it, and if too hard, it may remain for a longer time in the furnace, or wrought-iron or scrap may be added. The crude iron or metal may be made to contain variable proportions of carbon, but it is preferred to work it in the first operating furnace, so that it may contain about 1 per cent. With this percentage of carbon in it, it will not, under the influence of the ordinary temperature of puddling furnace, remain in a liquid state, but will settle to the bottom of the furnace in the form of a pasty and porous mass. In this state it would be unfit for being balled or hammered into wrought-iron, on account of its not having "come to nature," but it is suitable for being melted into steel.

As each load or charge of the crude iron or metal is added to the charge in the steel furnace, it will convey carbon to the mass about sufficient to compensate for the elimination of carbon which more or less results from open hearth melting; and when the furnace is charged, and it has been ascertained that the steel is fully melted, at the latter end of the process is added a small quantity of spiegeleisen, or ferro-manganese, in quantities not exceeding 5 per cent of the melted steel. A flux may be used in the steel melting hearth, such as oxide of manganese, lime, and salt, and alloys may be added, such as those of titanium or wolfram. The melted steel when ready is tapped out direct into ingot moulds, or into an intermediate receptacle, and thence into ingot moulds. The moulds may be fixed on a carriage, which is pulled up to the tapping hole by means of gearing. In the interval a plug of clay or iron may be placed in the tapping hole. The hereinbefore described process is adapted for the treatment of various qualities of cast-iron or pig-iron, but more particularly to that class which contains elements such as sulphur and phosphorus, and unless their entire or partial removal is effected, the quality of the steel produced will be materially impaired. In carrying out this process it is preferred that the crude iron or metal, previous to its being placed on the melting hearth, should be heated in a chamber, by preference one connected with the steel furnace. The hearth of the steel furnace may be lined with a material suitable for withstanding the high temperature, such as sand, or with best qualities of fire-clay or brick, or other refractory materials.

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CHARLES ATTWOOD, Walsingham.—Patent dated 10th March, 1868.

This invention of an improved method or methods of making cast-steel, and of making iron of a steely character, which is called steel-iron, as being a kind of iron approximate to steel, consists as follows:—The material employed may consist of such metal, whether in the state of iron or in that of steel whilst still in the melted state, as may have been previously brought out of the state of non-malleable or crude cast-iron into such a degree of decarburisation as to have become malleable, by the means of blowing through it or into it whilst in a melted state a blast or current of atmospheric air, according to the process well known to metallurgists by the designation of the "Bessemer process;" or which may have been brought into such a condition by any other means of applying either atmospheric air or other substances containing oxygen to such crude metal in the melted state, either beneath the surface or otherwise; and crude cast-iron or non-malleable iron, either in a melted or in a heated state, or otherwise if in any case more convenient, in either a heated or in a cold state—which ingredients are mixed together in the hollow or excavated hearth or bottom of a suitable reverberating furnace, in such manner or manners as hereinafter described, and in such proportions as under a very high and sufficiently continued heat may bring the whole mass, while in a state of fusion, to the proper chemical or metallurgical condition or quality of such descriptions of hard or soft steel, or of steel-iron (or steely-iron) respectively, as it may be intended to produce; after which the furnace is tapped, and the metal drawn off either directly into ingots or other moulds, or indirectly by tapping it previously into ladles, as may be found in any case more convenient.

As regards the kind of reverberating furnace to be thus employed, it is found that though a furnace similar to the common iron-founder's reverberating furnace, heated by coals burning upon the usual kind of grate, is capable of giving sufficient heat to so liquefy or hold in liquefaction the said mixture; yet, inasmuch as the obtaining and maintaining a higher and more uniform temperature, and by means of a flame more free from ashes and from sulphur than from such furnaces and grates can be obtained, and also insomuch as no considerably greater quantity of oxygen should pass into or through the melting chamber than may be readily for the most part absorbed or consumed by the carbonaceous or other gases of the furnace, it is preferred to employ a furnace heated by the combustion of gases, such as carbonic oxide or carburetted hydrogen, or other hydrocarbonaceous matters, according to any known or suitable method of employing them in furnaces; and the sort of furnace well known and used for steel melting called the "Siemens's regenerating furnace" is found to be very suitable and effective for the purpose, although the same result may also be obtained by other furnaces and other modes of burning such or similar combustible gases, such as persons skilled in such operations may preferably construct and employ. The furnaces must have a tapping hole, which may be similar to such as is usually used in ordinary iron-founders' reverberatories, and which may best be placed at or about the middle or deepest part of the excavated sole or hearth thereof, and so that it may be stoppered up in any manner usual or convenient in such furnaces. There must be also openings at which to run in or charge the fluid, or solid metals or materials which may be employed, and for taking out such small quantities for testing as may be desired, which openings should be so constructed as to be well and speedily closed and luted up after using them.

The hollowed-out or excavated hearth of the reverberating chamber must be of such size and depth as the quantity of metal intended to be cast from each separate melting may require, and may contain either small quantities of, say, 3, 4, or 5 cwts. of metal, or as much as 3, 4, or 5 tons or more, according to the size of the ingots or other castings required, the time required for working off a charge of such large quantities being of course longer than in the case of smaller; but for which smaller quantities from one to three hours will generally be amply sufficient. The brick or stone work or foundation of the hearth should be covered, as usual in iron-founders' reverberatories, with siliceous sand in a moderate degree ferruginous, or better still with rather coarsely ground "ganister," well rammed down to a considerable depth or thickness of somewhere about 18 inches; which also may advantageously be itself covered to the thickness of from 6 inches to 1 foot with an upper layer of the same sand, or of ganister, which may preferably be ground and mixed to the extent of about one-eighth of its weight with a somewhat fusible sort of sand, or loam, such as is well known to and used by iron-founders, by the name of "Woolwich loam." The inside walls and the arch or crown of the furnace may advantageously be made of "ganister bricks," or of the sort of bricks called "dinas bricks."

The proportions in which the two kinds of metal are to be used must vary according to the degree in which the malleable metal is used, as the material may have been previously more or less completely decarburised, or brought into the state of hard or soft steel, or of hard or soft iron; but by way of general rule, it may be mentioned that in any case in which that decarburisation may exist to about the same degree to which it is usually carried in well-puddled bar iron, a mixture of crude or cast-iron therewith, in the proportions of about from 8 to about 15 per cent of the total or mixed mass of metal, will yield a more or less soft or hard steel-iron; whilst the mixture of such crude metal in the proportion of from about 15 to about 40 per cent of such total mass, will give either such a soft or such a hard steel as may be suitable for most of the various purposes for which steel is generally employed.

As regards the mode of mixing the materials, it is preferred that the crude or non-malleable metal which may be employed should be melted in the reverberating furnace itself before the addition of the other material; though otherwise it may, where more convenient, be conveyed into the said furnace out of some other furnace or vessel whilst in a melted state, and in either case it should be brought to a state of liquefaction before the addition of the decarburised material. And inasmuch as it may sometimes be convenient for purposes of economy, or otherwise, to add to these materials in the reverberating furnace a greater or less proportion of steel, or of such steel scrap as it may be desired to work up and bring into the state of cast-steel ingots; such addition may be made either by adding it to or liquefying it at first along with the crude cast-iron, or else by mixing it with the other materials, and it may either be added in the cold or in the melted state to the metal in the furnaces.

It is usual in the practice of what is called "the Bessemer process" to first decarburise the iron, and then to add to it while in the converter, and still fluid, as much crude metal, also in the liquid state, as is judged sufficient for converting it to steel. And in that state those mixed materials in the state of steel may then be passed into this furnace and brought, by continued liquefaction, either with or without commixture with a further quantity of either crude metal or decarburised iron, as may be necessary, to such a condition in respect of quality or hardness as may be desired. It is considered more convenient, however, not to previously make such mixture with crude metal in such converter, but to pass the metal, decarburised as nearly as may be to the same degree as is the case with well-puddled bar iron, into the reverberating furnace as soon as that degree of decarburisation may be arrived at; when the required proportions of crude and of decarburised materials will mix and combine more perfectly at the high and continued temperature which can be maintained therein than they usually do in the said converter; the value of this process in great degree consisting in the much more uniform quality to which the steel or steel-iron can thus be brought, and in the more homogeneous and sound quality of the castings than can be obtained when cast directly from the Bessemer or any other converters. Nevertheless, in cases where such mixture of decarburised and crude or non-malleable metals may have been actually made in such converters or converting vessels, or in cases where by nature of any other process or processes of decarburisation which may have been employed, the metallic results may have been brought into a similar state of steel or of steel-iron, as the case may be, the contents may still be transferred into the reverberating furnace; in which furnace, either with or without such mixture with crude or non-malleable iron, or with decarburised iron, as may in any particular cases be, as before said, necessary, it may be continued sufficiently long for combination or for settling out the bubbles of gas or air, and then be cast into sound and homogeneous ingots or castings of the quality and in the form required. But in every case the quality of the metal to be produced will be better or worse according as the metallic materials employed may be such as, by their own proper quality and nature, are capable of producing steel and steel-iron of better or worse quality when used for such production by the more usual processes of manufacture employed for that purpose.

## THE PRACTICAL APPLICATION OF SPECTRUM ANALYSIS TO THE BESSEMER FLAME.*

THE present employment at Neuberg and Gratz in Austria of spectrum analysis to the Bessemer flame forms, as far as we can make out, the first actual practical application of spectrum analysis to this important purpose. Upon this fact we feel all the more called upon in simple justice to insist, as the number of the "Philosophical Magazine" for last December contains a paper by Dr. W. M. Watts, formerly an assistant of Dr. Roscoe of Manchester, in which are statements that we feel bound to contradict from personal knowledge. It is well known that Dr. Roscoe was the first to propose, "in the form of a short preliminary notice in the 'Proceedings' of the Manchester Literary and Philosophical Society for February 24th, 1863," the practical employment of spectrum analysis in the Bessemer process. All this is quite correct, but Dr. Watts also states that "an important practical result of the observations on which these communications were based was the discovery that the exact point of decarbonisation could be determined by means of the spectroscope with much greater exactitude than from

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* The Engineer, Feb. 28, 1868.

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the appearance of the flame itself; the change in which indicating the completion of the process is minute, and requires a lengthened experience to detect with certainty. This method of determining the point at which it is necessary to stop the blast was, indeed, at that time (1863) in constant use in Messrs. Brown's works at Sheffield, and has since been introduced with equal success by Mr. Ramsbottom (at the suggestion of Dr. Roscoe), at the London and North Western Railway Company's steel works at Crewe." So far is this from being the case now that the spectroscope has long been abandoned at the Atlas Works; and, after a most persevering series of experiments, conducted under the direction of Dr. Roscoe himself, the spectroscope has long been abandoned at Crewe, so that the merit, as will be seen from the following, of the actual practical application in this way of the spectroscope is due to Professor Lielegg.

With the exceptions of a short note by Professor Roscoe (" Proceedings" of the Literary and Philosophical Society of Manchester, vol. iii., p. 67, 1863), and of a lecture in May, 1864, by the same gentleman, before the Royal Institution, no scientific work on the spectral analysis of the flame of the Bessemer converter has been published before the researches made known during the last year by the Austrian Professor A. Lielegg, and printed amongst the reports of the "Proceedings" of the Imperial Academy of Sciences at Vienna. The main result of Professor Lielegg's observations is that, by the aid of the spectroscope, both the beginning and the end of the decarbonisation of the iron can be accurately determined; further, that a particular part of the refining period characterised by the appearance of bluish-violet lines, is observable only in the spectroscope; and, finally, that the appearance and disappearance of these lines may be employed as the means for determining the end of the charge.

It is a noticeable fact that, since the conclusion of Professor Lielegg's experiments, the spectroscope has for some time been constantly employed at the Bessemer works of the Austrian Southern Railway at Gratz, and has come into use at the works of the State at Neuberg. The instruments employed in the experiments were at first a simple spectral apparatus, without either a combination of lenses to keep the entering rays of light parallel, or a magnifying telescope, but consisted merely of two prisms, fastened according to the angle of smallest refraction to the bottom of a small closed wooden box blackened inside. On the one side of the same it is provided with a telescopic tube, having a slit so arranged that the rays of light entering fall upon the middle of the first prism; the spectrum is observed with the naked eye through a properly-situated cleft in the box. Bright daylight rays give a spectrum in which the stronger Frauenhofer lines are distinctly recognisable. The spectrum is small, but very distinct and bright; on which account the slit must be made very narrow, and this precautionary measure is also necessary in observing the Bessemer flame, on account of its great illuminating power, as otherwise the brightness of the lines would be almost equal to that of the background. Subsequently a larger spectroscope was employed. The latter instrument was provided with a telescope having a magnifying power of six, and with two prisms, each with an angle of refraction of 60 deg. Both prisms were adjusted to the minimums of deviation for the line D. The apparatus was also provided with a Steinheil scale tube for measuring the lines. Both spectroscopes were manufactured in the workshops for philosophical instruments at the Polytechnic Institution in Vienna.

The spectrum peculiar to the Bessemer flame, which makes its appearance at the commencement of the boiling period, and attains its greatest distinctness during the first half of the refining period, is—without regarding the lines proceeding from the potassium, sodium, and lithium spectra —simply the spectrum of burning carbonic oxide. The spectrum contains several characteristic lines and groups of lines, the respective positions of which were determined by a scale of lines dividing the space between the two characteristic potassium lines, K $\alpha$ and K $\beta$, into 255 equal parts. The result of the observations during eight charges were as follows:—

| | | |
|---|---|---|
| | 259 | K α (potassium line). |
| | 233 | Li α (lithium line). |
| α | 212<br>210<br>208 | Group of three narrow red lines, of which the first and third were mostly distinctly visible. |
| | 204 | Middle of a broad dark line of absorption with indistinct borders. |
| | 201 | Sodium line. |
| | 200 | Narrow dark lines. |
| β | 195<br>190<br>184 | Group of three greenish yellow lines, of which the third (184) is the brightest, and is always the first to appear; when the flame is very luminous, the whole space, from 199 to 184, appears filled with greenish yellow lines. |
| γ | 174<br>172·5<br>171·5 | Group of three light green lines, the third (171·5) is the brightest and first to appear. |
| | 167 | Bright green lines only visible during the refining period. |
| δ | 162<br>160<br>158<br>155·5 | Group of four greenish blue lines of equal brightness. |
| ε | 148<br>144·5<br>141<br>136·5 | Group of four equally bright light blue lines. |
| | 113 | End of a group of several blue equi-distant lines immediately following the last line (136·5) of the former group; the lines are much less luminous, and are not even always visible. |
| | 81<br>67 | Borders of a group of four bluish-violet double lines, only visible in the refining period, but not always distinctly. |
| | 41 | Bright clearly bordered bluish-violet line, appearing in the refining period simultaneously with the group (81—67). |
| | 4 | K β, second characteristic potassium line. |
| η | 2 | Bright violet line. |

The groups of lines marked α, β, γ, δ, and ε, and the line η characterise the Bessemer spectrum, and this is completely identical with the spectrum of the carbonic oxide flame observed during the preparatory heating of the converter with coke. With regard to the other lines which appear only during the refining period it cannot be affirmed with equal certainty that they proceed from the carbonic oxide spectrum—although this is exceedingly probable—as the high temperature during this period may possibly cause the volatilisation of other substances, either from the molten iron or from the lining of the converter.

The general character of the Bessemer spectrum coincides with the other spectra hitherto produced by the combustion of gases containing carbon, and all that Attfield (Edinburgh Phil. Tran., vol. xxii., p. 224), Dibbits ("Spectral Analyse, Tassemeyer in Rotterdam, 1863"), Plücker (Trans. of the Roy. Soc., London, vol. clv., part i., p. 15), and others have said concerning the peculiarities in colour and grouping of the lines, refers also to the Bessemer spectrum, for it possesses exactly the same groups of lines as the spectra of ordinary coal gas, of elaidin, and of cyanogen, but their relative position is different, according to the observations of Professor Lielegg.

While in the spectra of cyanogen and of ordinary coal gas the three groups, following one after the other in the yellowish green, green, and blue parts, coincide completely, not one of the groups in the Bessemer spectrum coincide in position with those of either the above-mentioned or any other spectra. Another remarkable difference is to be found in the varying luminosity of the single lines. In all hitherto-examined carbon spectra the line of each group which is the least refracted is the brightest, while the following lines become duller; in the Bessemer spectrum, on the other hand, exactly the contrary is the case with the groups $\beta$ and $\gamma$, and in the groups $\delta$ and $\epsilon$ there is no difference at all in the luminosity of the respective lines amongst one another.

The above-mentioned differences give the spectrum a certain peculiarity, and if one considers the chemical nature of the carbonic oxide, which does not admit the supposition that carbon is separated during the combustion, one may very well conclude that the Bessemer spectrum proceeds from the incandescence of the carbonic oxide, and not of the carbon.

In conclusion, we may add that attempts to absorb certain parts of the spectrum by means of coloured glasses, in order to increase the distinctness of others, did not lead to any noticeable results.

The following observations were made with regard to the development of the Bessemer spectrum in the different periods of the process, and the connection between the alterations in the spectrums and those in the flame of the converter, during a series of charges of grey charcoal pig-iron. At the beginning of the charge there was a weak continuous spectrum, the yellow part quite invisible, the blue and violet part very weak and indistinct, even the sodium line was absent. The latter highly remarkable fact, considering the great delicacy of the sodium reaction, can hardly be owing to the absence of vapours of sodium salts, or to an insufficiently high temperature, but must be ascribed to another cause. The flame, during the slag-forming period, is, namely, not a real flame, as it is not formed by burning gases, but by a number of ejected sparks. After this period has continued a certain time, the luminosity and size of the spectrum increases, and after one minute at the most, subsequent to the first greater ejection of slag, frequently, however, at once, the sodium lime flashes out; after one or two minutes more it remains distinctly visible up to the end of the charge.

From this appearance the commencement of the boiling period is characterised, for as soon as the sodium line becomes perfectly visible, one line in each of the greenish-yellow, green, and violet parts of the spectrum may be observed, and just as the practised eye of the metallurgist detects by the appearance of carbonic oxide in the flame the change of period, so the same change is also characterised by the appearance of these first carbonic oxide lines in the spectrum. The lines which appear first are:—184 of the group $\beta$, 171·5 of the group $\gamma$, and the violet line 2, marked $\eta$ (the last line lies just next to the potassium line K $\beta$, but is only seen separate from the latter when the slit is very narrow; when the slit is wider, both lines touch, forming one broad violet stripe; the size of the slit is then the best when the distance from the one line to the other is the same as their own width).

During the boiling period the flame increases greatly in size, is flickering, drawn out, and exhibits sometimes internally a yellow cone. The development of the spectrum proceeds with that of the flame. The line δ and ε appear, the groups β and γ become completed, and at last the red lines of the group α also appear. When the line is very clear and distinct, a number of weak blue line are seen next to the line 136·5 of the group ε, and fill up the space up to 113.

On account of the varying brightness of the light from which the spectrum proceeds the latter is inconstant in appearance during this period, not, however, as regards the bright lines, but only as regards the dark shadowings, which are doubtless lines of absorption. The dark stripes denoted 204 and 200 remain, however, unchanged.

During the now following refining period the flame assumes a peculiar form, and a considerable increase in temperature and luminosity, and the lines in the spectrum attain now their maximum of brightness. But the commencement of this period is not so accurately determinable as that of the boiling period. Very characteristic of this period, however, is the appearance of fresh lines in the bluish-violet part of the spectrum. From four to six minutes previous to the end of the charge, therefore, just during the next intense refining process, a group of four blue equidistant lines (81 to 67) becomes visible, each having the appearance of a double line. Shortly afterwards a very bright and sharply defined bluish-violet line (41) also appears. These lines remain visible during some minutes, at the close of which, first the single line (41) and then the group (81 to 67) disappear. The whole spectrum then becomes duller, a sign of the closely approaching end of the decarbonisation. The luminosity of the background remains unchanged, whilst that of the lines diminishes, and at last the lines disappear in rather rapid sequence, in the reversed order of their former appearing, until only the two lines (184 and 171·5) remain visible—at this moment the charge is generally finished.

From the above details it will be perceived that by the aid of the spectroscope both the beginning and the end of the decarbonisation of the iron may be accurately determined. It only remains to be said that the above experiments of Professor Lielegg were made in the Bessemer works of the Austrian Southern Railway at Gratz in Styria.

As an addition we give here the results of a personal inspection in January last by a foreign correspondent of the process as carried on at the Bessemer works at Gratz. Here the requisite quality of steel—No. 5, hard, or No. 6, soft—is always invariably obtained. At five minutes past two 66 cwts. of grey pig-iron melted in a reverberatory furnace were run into the converter; at twenty-one minutes past, the yellow sodium line (201) first became visible, and at thirty-six minutes past two the carbonic oxide lines in the spectrum vanished entirely, and the converter was turned down to receive the charge of 5½ per cent of spiegeleisen. According to the statement of the conductor of the process, Mr. Kupelwieser, the quantity of carbon present in the converted pig-iron at that moment is invariably 0·03 to 0·04 per cent. After the addition of the spiegeleisen the converter remained unmoved until a quarter to three, when its contents were poured into the casting ladle.

In conclusion, however, we must not omit to remark that the application of the spectroscope has still occasionally difficulties to overcome. Thus, although it has hitherto been always perfectly successful at Gratz, at the Imperial Works at Neuberg the conclusion is often obscured by the dark smoke exhaled at this period from the mouth of the converter, which causes the spectrum to lose its distinctness. The reason of this is difficult to ascertain. Perhaps it lies in the fact that at Neuberg the pig is run direct from the blast furnace, whilst at Gratz it is re-melted in a reverberatory furnace; or what is more probable, it is caused by an excess of manganese or silicium. The latter hypothesis is supported by the results of an approximate analysis of a small quantity of this smoke obtained at Neuberg by means of a wrought-iron tube inserted into the mouth of the converter. The condensed product contained 36 per cent of silica, 16 per cent of protoxide of iron, and 48 per cent of protoxide of manganese. Neuberg pig-iron, as compared with most other Styrian pig-irons, is generally richer in silicium and manganese. Thus Neuberg pig-iron contains from 2 to 2½ per cent of silicium, and 2 to 3, and more per cent of manganese.

The following further details regarding the dark brown vapour evolved from the mouth of the Bessemer converter towards the end of the process, in quantities varying with the nature of the pig-iron, may not prove uninteresting. As this phenomenon exhibits itself in a much greater measure during the Bessemer process as carried out at Neuberg than at Gratz, Mr. Schöffel, assistant chemist at the Leoben College laboratory, undertook to collect a quantity of vapour at the former place for analysis. In order to obtain the vapour in perfect purity, a bent wrought-iron tube ½ an inch in diameter was inserted into the mouth of the converter and connected by means of a short india-rubber tube with a glass receiver. The total length of the tube was about 9 feet, and the mere pressure of the blast was sufficient to drive the vapour through the same. By the time the vapour reached the tube it had cooled down to the ordinary temperature and condensed on the sides of the receiver in the form of a very voluminous light *white* powder. From a very careful analysis of this powder its exact composition was found to be:—Silica, 34·86 per cent; protoxide of iron, 16·29 per cent; and protoxide of manganese, 48·23 per cent. Mr. Paul Kupelweiser, the gentleman who introduced the use of the spectroscope at the Bessemer Works at Gratz, and who has been constantly conducting the Bessemer process there by aid of the same during several months with various kinds of pig-iron, is of the opinion that the evolution of this vapour increases solely with the amount of manganese in the pig, and this opinion is supported by the result of the above analysis of the vapour, in which the manganese is present to the amount of nearly one-half. It need scarcely be added that the difference in colour between the vapour as seen evolving from the mouth of the converter and that as seen condensed, proceeds merely from the different conditions of light.

## LÜRMANN'S SLAGGING SYSTEM.*

AN improvement in the hearth of blast furnaces, to which reference was made in the *Mining Journal* of Dec. 14 last, has recently excited great attention amongst German and American ironmasters. As is well known, the present furnaces have an opening of the hearth in the front, which is the source of many defects. In Austria, the charcoal furnaces have the hearth completely closed, and give, therefore, much better results in comparison with coke blast furnaces. M. F. Lürmann, engineer of Georg Marien Hütte, near Osnabrück, tried to apply the closed hearth system to coke furnaces; but, owing to the great pressure of blast, the heat, and corroding nature of the scoria, he failed. But being convinced of the great advantages of the closed hearth, he persevered in his experiments, and at last overcame all the difficulties. The principal features of his invention are the doing away with the tymp, fore-hearth, and dam, in carrying the walls of the hearth to the bottom on all sides, and the scoria outlet. This scoria outlet is made of metal, and dovetailed in a plate (the scoria plate) which is fastened into the wall of the hearth. The scoria outlet and plate are provided with canals, through which cold water is kept circulating, The working of the furnace is very simple. After tapping, the blast has to be put off, and the tapping hole, as well as the scoria outlet, to be filled with sand or clay; then the blast is put on with full pressure, and remains so until the next tapping, even if it should be required to replace the scoria outlet by another. The hearth soon will be filled with metal and scoria; as soon as the latter is observed at the tuyeres the scoria outlet (which is several inches below the tuyeres) is opened by means of an iron or steel bar and a hammer, when the scoria will flow off in a continual stream. The advantages of this system are evident. There are no repairs of tymp, &c., no bar-working—in short, the management of the furnace has become very simple, and may even be trusted to less experienced smelters. But the greatest advantages are the saving in time and fuel; the stoppages are lessened materially, they are nearly *nil.* Most ironmasters do not heed the many short stops, and have, therefore, scarcely any idea how much time they lose. At Georg Marien Hütte it has been the custom for many years to notice every stoppage minutely; compared with the working time, the lost time amounted to 9¼ per cent. It may be confidently asserted that at most ironworks the loss of time is much heavier.

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* Mining Journal, Aug. 22, 1868. American Journal of Mining, Nov. 9, 1867; April, 1868. B. u. h. Ztg., 1867 and 1868.

The scoria outlet and plate take but little space. The room formerly occupied by the open fore hearth has now become available for another tuyere, so that it is in the power of the metallurgist to have the blast equally distributed. The blast may be raised to any pressure, as a throwing out of materials is out of question. The heat is thus greater, and better kept together, which accounts for the saving of fuel and for the increase of the make of pig-iron. The higher pressure of blast makes this improvement very valuable when coal and anthracite are used. In Catasauqua, Pa., U.S., Lürmann's system had been successfully tried, and is now spreading round rapidly. The invention has been lately patented in this country by M. C. Holste, of Henrietta Street, Covent Garden, and an eminent firm in the Clevelend district intends to try it on a large furnace of 80 feet high and 25 feet in diameter, now building; the result, which is looked forward to with much interest, will be made known as soon as possible. Excellent testimonials have been obtained from German and American ironmasters, and it may be mentioned that in one of them the writer seems to have had a good deal of misgivings, which have now fully disappeared. Subjoined are a few authenticated facts.

RESULTS OF THE BLAST FURNACES AT GEORG MARIEN HUTTE, NEAR OSNABRUCK, IN THE LAST THREE YEARS.

| | 1865-66. | | | | 1866-67. | | | | 1867-68. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Furnace. | In Blast | Stoppage. | | | In Blast. | Stoppage. | | | In Blast. | Stoppage. | | |
| | days. | h. | m. | per cent. | days. | h. | m. | per cent. | days. | h. | m. | p.c. |
| No. 1 .. | 345 | 742 | 20 | 8·93 | 85 | 85 | 30 | 4·20 | 366 | 324 | 25 | 3·7 |
| No. 2 .. | 365 | 783 | 55 | 8·95 | 297 | 551 | 10 | 8·19 | 274 | 316 | 10 | 4·8 |
| No. 3 .. | 365 | 857 | 35 | 9·80 | 365 | 821 | 30 | 9·38 | 72 | 139 | 5 | 8·0 |
| No. 4 .. | 52 | 123 | 10 | 9·80 | 365 | 667 | 30 | 7·59 | 366 | 456 | 25 | 5·2 |
| Total.. | 1127 | 104 d. | 10 h. | 9·24 | 1112 | 88 d. | 13 h. | 7·96 | 1078 | 51 d. | 12 h. | 4·78 |
| Actually in blast.. .. | 1023 days | | | | 1023 days | | | | 1027 days | | | |

The closed hearth system was not in use in 1865-66; in use on two furnaces towards the end of 1866-67; in use on all furnaces in 1867-68.

No. 3 is now re-building; Nos. 1 and 2 are built on the principle which was applied to No. 4, whilst in blast, where also many alterations were made without stopping the furnace. The stoppages at present are mainly caused by tapping and the cleansing of the gas pipes, required every ten days, and lasting from three to three and a half hours, the gas containing a deal of zinc, and the ore being in the form of dust. The other results were:—

| | 1865-66. lbs. | 1866-67. lbs. | 1867-68. lbs. |
|---|---|---|---|
| Ore and flux . | 255,953,270 | 260,665,195 | 331,640,020 |
| Coke . . . | 119,363,900 | 126,565,300 | 149,602,300 |
| Pig-iron made | 60,820,808 | 64,947,780 | 83,404,310 |

Per 1000 lbs. pig-iron have been used—

| | 1865-66. | 1866-67. | 1867-68. |
|---|---|---|---|
| Ore and flux. . . . . | 4204 lbs. | 4008 lbs. | 3976·3 lbs. |
| Coke . . . . . . . . | 1963 lbs. | 1945·7 lbs. | 1792·5 lbs. |
| Yield from charge, per cent | 23·79 | 24·95 | 25·15 |
| Average make per day and for each furnace. . . | 53,996 lbs. | 58,406 lbs. | 77,367 lbs. |

The iron made is foundry iron, spiegeleisen (first quality), and Bessemer grey pig-iron; the principal consumer of the latter is M. F. Krupp, the steel manufacturer, at Essen, and the make of it has been, in 1867-68, three times as large as in 1865-66. As is well known, this sort of pig-iron requires more fuel than ordinary iron, which should be borne in mind when comparing the above figures. The furnaces at Georg Marien Hütte are of various sizes, one of them, for instance, makes 130,000 lbs. German per day (65 tons).

Another ironwork, the Ilseder Hütte, near Peine (Hanover), applied the improvement to its two furnaces in February last, whilst in blast, with the following results:—

| 1868. | Make. | Make per day. | Working Expenses per 1000 lbs. | | | |
|---|---|---|---|---|---|---|
| | lbs. | lbs. | thr. | gr. | pf. | |
| January . | 4,807,400 | 155,077 | 7 | 3 | 2 | (21s. 3·82d.) |
| February . | 5,016,600 | 172,986 | 6 | 17 | 7 | |
| March . . | 6,253,000 | 201,720 | 6 | 1 | 8 | |
| April . . | 6,585,600 | 219,520 | 5 | 24 | 5 | |
| May. . . | 6,674,000 | 215,290 | 5 | 17 | 4 | (16s. 8·83d.) |

The results of Mr. F. Krupp's furnace at Mühlofen, on the Rhine, were—

| | Ore and Fuel. lbs. | Coke. lbs. | Pig-iron. lbs. | Per 1000 lbs. Pig-iron. Coke. | Yield from Ore. per cent. |
|---|---|---|---|---|---|
| In the first twenty-three days of the previous blast from Nov. 17 to Dec. 8, 1866. .. .. | 2,019,500 | 959,050 | 695,600 | 1454 | 32·6 |
| In the first twenty-three days of the present blast, July 9 to 31, 1868.[*] .. .. .. .. | 3,226,700 | 1,132,920 | 975,300 | 1161 | 30·2 |
| Difference .. .. .. | 1,207,200 | 173,870 | 315,700 | 293 | 2·4 |

The saving in fuel alone amounts, therefore, to about 20 per cent, leaving alone the increase of make and the saving in labour, &c. The furnace formerly had three tuyères, now it has four, which are regularly distributed, made feasible by the doing away with the fore hearth.

The Carbon Iron Company, at Parryville, Pa., communicated to M. Lürmann's agent in New York the following on May 23, 1868:—

"The 'Prussian Furnace,' our No. 1, made 182 tons of iron last week; it has been in blast seven weeks. In the seventh week of the previous blast it made 129½ tons, which gives us an increase of 52½ tons. Comments with such figures before us would be superfluous. Please accept my thanks for calling my attention to your improvement.

JAMES THOMAS, Superintendent."

## M. CARON'S METHOD OF PURIFYING IRON.[†]

CARON has recently published a paper on the employment of fluoride of calcium in the purification of iron ores containing phosphoric acid. Some six years ago he minutely examined the action of manganese on cast-iron, and found that by means of this metal, nearly the whole of the sulphur and silicium could be extracted from cast-iron, whilst the phosphorus present was unaffected. To destroy the injurious action of the phosphoric acid it is customary to mix the ore with lime, by which means alone it was thought the iron could be deprived of its phosphorus. As, however, the phosphate in question unfortunately became, by the addition of lime, less, or no longer fusible, it was necessary to mix with them at the same time sufficient silicic acid to give the slag the requisite fusing point. In this operation were brought together phosphate, silicic acid, and carbon, just as in Wöhler's process for the production of phosphorus; and phosphorus was of course set free to form a phosphide with the iron. That such a change actually takes place is shown by an examination of the slags of blast furnaces, in which phosphatic iron ores are smelted; such slags are free from phosphorus, whilst the cast-iron always contains this substance, rarely in quantities that can be considered injurious. Granted that the lime removes the phosphoric acid from the oxide of iron, it is still requisite that a fusible substance, and another than silicic acid, is added, which is able to dissolve the phosphate of lime without decomposing it. Such a material is fluoride of calcium, as the following experiment clearly shows. A quantity of phosphate of lime and fluoride of calcium were placed in a plumbago crucible, enclosed in a Hessian crucible, the insterstice being filled with a layer of charcoal. And at the same time a mixture of phosphate of lime and silicic acid were filled into another similar crucible. Both crucibles were heated to the temperature at which steel melts. The carbon crucible, filled with silicic acid and phosphate of lime, was porous, and contained nothing but silicate of lime, the phophorus having disappeared. The other crucible, on the other hand, in which the fluoride of calcium was placed, had undergone no change, only a thin layer of graphite had been acted upon, due, doubtless, to the silicic acid which it contained. The fused contents of this vessel contained phosphorus, and emitted light when subjected to blows from the hammer. Thus, it is shown that fluoride of calcium can dissolve phosphate of lime without decomposition occurring.

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[*] Lürmann's system was adopted on this occasion.

[†] The Engineer, Nov. 27, 1868.

A second series of experiments was made with phosphate of iron. In a hollowed-out crucible was placed the requisite amount of pure phosphate of iron, lime, and fluoride of calcium, and in another the former substance, together with lime and silicic acid; both crucibles were then raised to the temperature before-mentioned. The crucible containing the silicic acid showed signs of having been corroded, and the fused contents were crystallised in large plates, which were very friable. The crucible containing the fluoride of calcium had, on the other hand, remained nearly intact; the melted mass could be flattened out under the hammer, and gave a very uniform fracture. The product from the former crucible contained about three times as much phosphorus as that from the latter.

When working with phosphatic ores containing small amounts of phosphorus—as phosphate of iron—we obtain, on substituting fluoride of calcium for silicic acid, a decidedly better product. The advantage derived is, however, the smaller the less the quantity of phosphate present in the ore.

Not alone phosphates dissolve in fluoride of calcium without decomposition; sulphates, arsenates, &c., comport themselves similarly. Alumina and analogous substances are likewise dissolved under these circumstances, and are to be found in the slag, without silicic acid having been used as a vehicle. In fact, the power of fluoride of calcium to take up aluminium had already enabled Caron to prepare well-developed crystals of corundum.

## GJERS'S MANUFACTURE OF CAST-STEEL AND HOMOGENEOUS IRON.*

In treating puddled steel, raw steel, and puddled iron for the production of cast-steel and homogeneous iron, the material to be treated has usually been (at great expense) balled and shingled to clear it from the cinder, and subsequently generally rolled into bars, cut up in pieces and re-melted. According to an invention recently patented by Mr. John Gjers, of Middlesborough, when crude iron or refined iron is caused, through the action of iron cinder or other additional matter, to boil and to come to nature, the material is transferred under treatment from the puddling, even before the process of balling. By re-melting or keeping fluid the material, it is caused to separate from the cinder and to attain an uniform quality ready to run into ingots. Thus Mr. Gjers melts crude pig-iron, or refined iron, or re-carburised puddled iron, and works it in the usual way in a puddling furnace, and causes it through the action of rich pure iron cinder, or other additional matter commonly used when making puddled steel—such, for instance, as manganese and salt—to boil and to come to nature in the manner adopted for making puddled steel or puddled iron. At or before the stage called top-boil, just before the metal begins to thicken and to come to nature, but before the stage when it is fit or ready for boiling-up, the material under treatment is tapped with as much of the cinder as cannot at this period of the process be separated. It is transferred into receptacle, in a reverberatory furnace on Siemens's regenerative principle. It may also be run on to the open hearth of a reverberatory gas furnace, which may be either on Siemens's regenerative plan or on the blowpipe plan, in which gas is used in conjunction with a hot blast. The essential feature of the furnace to be employed is that it should be capable of producing a temperature sufficiently high to melt steel or homogeneous iron, and it is also important that the flame should be capable of regulation to either an oxidising or a carbonising flame.

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* The Mechanic's Magazine, Aug. 14, 1868.

Here, in the reverberatory furnace, Mr. Gjers allows the transferred metal in a fluid state to remain at rest for a length of time exposed to a neutral or to a carbonising or an oxidising heat, according as the crude steel metal requires more or less decarbonising, the heat being sufficient to keep it perfectly fluid until the metal has thoroughly separated from the cinder, which will float on the top, and until it has arrived at the requisite point of carbonisation to form the steel or homogeneous iron which may now be tapped into ingot moulds. Or the cinder may first be tapped or removed, and other flux (such as oxides of iron and manganese in the shape of pure ores of those metals) may, if necessary, be added to assist in decarbonising and to protect the metal. To the metal may be added a certain quantity of either wrought or crude iron, of the shape of spiegel iron or other matter (manganiferous), so as to arrive at the point of carbonisation and temper desired.

As far as possible the process is regulated so that the transference from the puddling furnace may be made at such a period of the coming to nature as will enable the metal, after having been made thoroughly fluid and remained so sufficiently long to decarbonise in the reverberatory furnace, to be obtained without addition of malleable iron or ore at the degree of decarbonisation desired. If the proper precautions are taken to boil and to work the iron well in a suitable cinder in the puddling furnace, it will generally be pure enough for steel. At the last stage of fluidity, while it is yet fluid enough to run, and just when it is about to congeal or come to nature, it still contains about 2 per cent too much carbon. By transferring and exposing it, for three or four hours, in the reverberatory furnace in a liquid state to a neutral or slightly oxidising flame under a cover of oxidising cinder, this excess of carbon gradually works off, and when it is worked down to the point desired (which may be ascertained by testing samples) it is tapped into ingots. To temper and improve the steel or homogeneous iron, in most cases before tapping the metal a small proportion of manganese in some of its combinations is added.

It has been found beneficial to let the metal decarbonise to an extent slightly below the desired degree of carbonisation of the steel or homogeneous iron, and then to improve and re-carbonise the metal by adding a small proportion of spiegel iron, amounting to about 1 per cent of the whole. The carbon may, in some cases, be partly reduced by the addition of wrought-iron, or, it may be, other malleable iron in any form containing less carbon than the desired steel. In practice, it has been found advantageous for this purpose to make use of scrap bars, blooms, or balls in a heated state, which are gradually introduced and melted with the fluid metal tapped from the puddling furnace. In some cases, cast-steel or homogeneous iron is made by using ordinary puddle balls in combination with the fluid metal tapped from the puddling furnace, for which purpose it is found convenient to partially tap or transfer the contents of the puddling furnace just before the metal comes to nature, and to allow one-half less or more of its contents to run out into the reverberatory melting furnace. The rest may be allowed to continue working in the puddling furnace until it has thoroughly come to nature, and has become malleable, and the cinder has dropped, when it may be transferred either by shovels or in lumps and added to the fluid metal previously tapped from the puddling furnace on to the hearth of the reverberatory melting furnace.

The whole of the metal thus mixed, after being thoroughly fluidified and brought to the desired point of carbonisation in the reverberatory steel melting furnace, may then be run into ingots; or four or more puddling furnaces may be employed to one melting furnace, and the entire contents of one or several of the puddling furnaces may be transferred before the period of coming to nature while yet fluid, and the contents of the remaining furnaces may be transferred after the contents have got into nature; the entire contents of the whole of the puddling furnaces may then be melted together in the steel melting furnace; or the crude steel metal tapped from the puddling furnace at the period named may, particularly when it is desired to treat it in crucibles, be run into moulds as flat cakes, which, being broken in pieces, may be re-melted in crucibles (or in the reverberatory furnace) in conjunction with malleable iron or with iron ore to form steel.

## PROCESS FOR CASTING STEEL UNDER HIGH PRESSURE.

By James Henderson.*

It is well known that cast-steel run into moulds is subject to blister, and is otherwise porous, which defect reduces considerably its toughness. In order to give the metal its requisite tenacity, it is subsequently re-heated and then rolled and hammered. As many articles, such as cannon, cannot be treated in this manner, I have devised to submit them to a high pressure, while in a liquid state, inclosed in their sand moulds maintained in iron flasks. For this purpose, immediately after running a cannon, I cover hermetically the head by a metallic cap, by means of bolts or other devices attached to the flask. This cap is fitted in its centre with a vertical pipe, and provided with a cock at lower extremity, while its upper extremity is closed by a washer pressed with a bolt in such a manner as to act as a safety valve. Before attaching the cap at supposing an inch from the surface of the liquid metal, I introduce in the vertical pipe and between the cock and the washer, a charge of about ¼ of an ounce of gunpowder, in the proportion of eighty parts of saltpetre and twenty of charcoal, with no sulphur. On opening the cock this powder falls on the metal, ignites, and engenders about ⅛ of a cubic foot of gas at 1400° C. These gases exert on the liquid metal a pressure, which is transmitted through the entire mass, thereby condensing the same and expelling the blisters. The effect thus produced is equivalent to the pressure of a head of liquid metal 90 feet high, admitting that the capacity between the cap and the surface of the metal contains 30 cubic inches. By making the flasks sufficiently strong, the charges of powder may be varied, so as to produce, by its ignition, a uniform and general pressure, which is preferable to the partial, irregular, and momentary action of a hammer.

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* Scientific American, May 2, 1868.

## MR. BESSEMER'S NEW SYSTEM OF HIGH-PRESSURE HOT-BLAST FURNACES.*

UNDER the title of "Improvements in the manufacture of cast-steel and homogeneous malleable iron, and the fusion or melting of different kinds or qualities of iron and steel and their alloys, and also in the construction and mode of working the furnaces and apparatus employed for such purpose," Mr. Bessemer has recently—10th of May last—filed the specification of another invention, which is said to be of great importance. Its main features may be regarded as an embodiment, for the purpose of fusing malleable iron and steel, of the experience gained by, and principles proved in, the Bessemer converter. It has long been understood that Mr. Bessemer has been directing his rare ingenuity to some good plan for melting old rails and similar work; and we suppose that this patent, forming by its length almost a volume on metallurgy, is one of the principal results. The system also appears to have already been thoroughly worked out in practice. Mr. Bessemer first of all refers to what is really the distinguishing feature of his converter—the rapid way in which it produces the required heat:—"Intensity of heat, rather than quantity, is the condition essential to the successful working of furnaces employed" in melting wrought-iron or steel containing little carbon. A substance which requires 3000° of temperature to produce fusion may be kept at a temperature of 2900° for whole days in succession without becoming thoroughly melted, when the mere addition of only 100° or 200° of heat would, in that particular case, have produced a complete fusion of the substance in a very short period of time. In order to obtain this intensity, or rapid development of the heat required, Mr. Bessemer has recourse to air at both a high temperature and a high pressure. Atmospheric air and other gaseous fluids in a heated state acquire a still higher degree of temperature by their compression "into a smaller space," "such increase of temperature being in proportion to their reduced bulk, or to the number of atmospheres forced into the space usually occupied by one." He therefore constructs furnaces of sufficient strength to withstand an internal pressure of two or more atmospheres, observing that he does not propose by this means to generate a greater quantity of heat by the combustion or union of a given quantity of carbon and oxygen than is obtained by such means in well constructed furnaces; for the compression of the gaseous products of combustion within a furnace does not generate heat, but merely concentrates into a smaller space, and gives greater intensity to the same quantity or number of units of heat as would have existed in a more diffused state had not pressure been applied. Hence, wherever the temperature produced by the combustion of fuel in ordinary furnaces, having a free escape to the chimney, is sufficient for any desired object—as, for instance, the evaporation of water in steam boilers—a loss would be sustained by compressing the gaseous products of combustion in such furnaces, for the amount of engine power required to compress the gases would exceed the power obtained from the increased quantity of steam generated in consequence of such compression, all other conditions being equal. But when the highest temperature produced in ordinary furnaces with a free escape is actually less, or where it only by small amounts exceeds the temperature absolutely required in any process, the case is entirely altered. Though a very high temperature, dependent on the pressure used, may be thus produced, Mr. Bessemer prefers, in order to have a moderate wear and tear in the furnace, a moderately rapid fusion. He states that, " in a small furnace using coke as fuel, with a cold blast of 20 lbs. per square inch and a pressure of 17½ lbs. in the furnace over that of the external atmosphere, small test pieces of cold wrought-iron were fused with great rapidity. For example, a piece of 2 in. square wrought-iron bar 12 in. long, weighing 13 lbs., was introduced cold into the furnace and was completely fused in five and a half minutes. In the same small furnace 3 cwts. of wrought-iron scrap were put in cold, and were poured fluid from the furnace after an interval of fifteen minutes. The furnace was then working with an average internal pressure of 15 lbs. to 16 lbs. per square inch in excess of the pressure of the external atmosphere."

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* The Engineer, July 9, 1869.

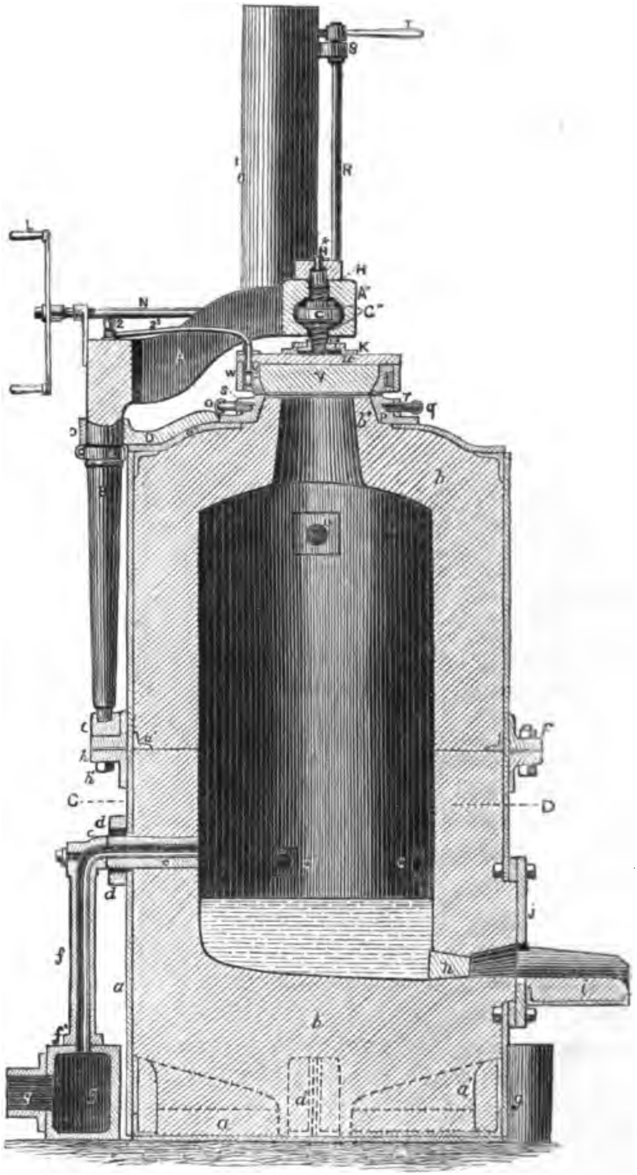
He believes " that a pressure of 20 lbs. to 30 lbs. over that of the external atmosphere will be found the most economical in practice, for it is probable that if a much greater pressure is employed it would raise the temperature so high as to drive the iron rapidly off in the form of vapour," as, in fact, generally occurs towards the end of the process in the ordinary Bessemer converter.

The materials to be melted in these furnaces are puddled iron or steel, finished iron or puddled steel bars cut into lengths, or steel purified by nitrate of soda, the crop ends of rails, old rails, ladle sculls, and other scrap. They are also to be employed in melting up the mixed steely metal for casting railway crossings, wheels, bells, anvil blocks, stamp heads, guns, mortars, and other articles.

The system is to be applied to cupola furnaces, crucible furnaces, and reverberatory furnaces. In all these cases the outer shell is preferably made of iron or steel boiler plate, with all the joints well caulked and made air-tight, and sufficiently strong to resist the internal pressure, though cast-iron shell may also be used. The furnace is to be lined with Stourbridge fire-brick, Dinas bricks, plumbago, or also ground ganister, on the plan now adopted for the Bessemer converter. To fuse wrought-iron or steel without so much reference to purity as to cheapness, Mr. Bessemer prefers to apply this system to a cupola furnace, having a dome through which the metal and fuel are admitted. The circular door is carried on a movable iron arm, which itself carries an upright cylinder with a movable bottom, and into which the charge of fuel and metal is put to be fed in. To preserve the door from the heat and prevent leakage of flame and gases, a hollow channel is made round the door frame, into which steam or air, at a higher pressure than that within the furnace is conveyed. The escape opening for the products of combustion can be altered in area by the insertion of small pieces of fire-clay. Several fire-clay tuyeres are used for conveying the heated blast, which is also at a pressure from 2 to 6 lbs. higher than that in the furnace. A plan is also shown whereby powdered materials may be conveyed by the blast into the furnace. The cupola can be taken in two in order to be able to line it, in the same way as the Bessemer converters are lined. To show the transformation operated on the ordinary cupola furnace by Mr. Bessemer, we have chosen this form for illustration, though the cupola on trunnions, like the ordinary Bessemer converter, may be regarded as a more perfect shape.

Fig. 125 is a vertical section on the line A B of Fig. 126; Fig 126 is a horizontal section on the line C D of Fig. 125; Fig. 127 is a front elevation of the furnace; and Fig. 128 a plan of the upper part of the same; and Figs. 129 and 130 vertical sections of the escape aperture. *a* is the outer shell of the furnace, formed of strong plates of iron, riveted and caulked air-tight, and having gusset pieces, $a^1$ to strengthen the bottom of it; *b* is an internal lining of fire-brick, plumbago, ganister, or other refractory material; *c*, *c* are fire-clay tuyeres moulded square externally, and having a round hole through them for the passage of the blast; they are inserted through the square iron frames, *d*, which are secured by counter-sunk rivets to the shell, *a*, and are bevelled on the inside; the outer end of the tuyeres, *c*, are enlarged or made taper, and the space between this enlarged part and the bevelled sides of the frames, *d*, is caulked with iron cement (iron borings and sal-ammoniac), so that the escape of gases from the furnace around the tuyeres is prevented, and the pressure of the flanges, *e*, of the blast pipes, *f*, against the enlarged end of the tuyeres is also prevented from forcing the tuyeres, *c*, into the furnace by reason of its enlarged end and the iron cement around it, while the blast pipe flanges, *e*, by being bolted to the iron frames, *d*, also prevent the internal pressure acting on the end of the tuyeres from driving them outward; the blast pipes, *f*, are bolted to the main air trunk, *g*, by flanges, $f^*$. An equilibrium valve is placed in the main pipe, $g^*$, near to the furnace, by means of which the blast may be turned on, or off, or moderated. The feeding door of these furnaces is so small that it is necessary to provide a special means of entering the furnace for re-lining the interior from time to time for the purpose of giving convenient access to all parts of the interior. The furnace is divided into two parts by massive angle flanges, *h*, *h*, which are faced so as to form an air-tight joint, and are secured together by bolts and nuts, as shown at $h^*$. When the furnace is to be repaired, the upper part may be lifted off with a crane, when the lower part will be readily

FIG. 125.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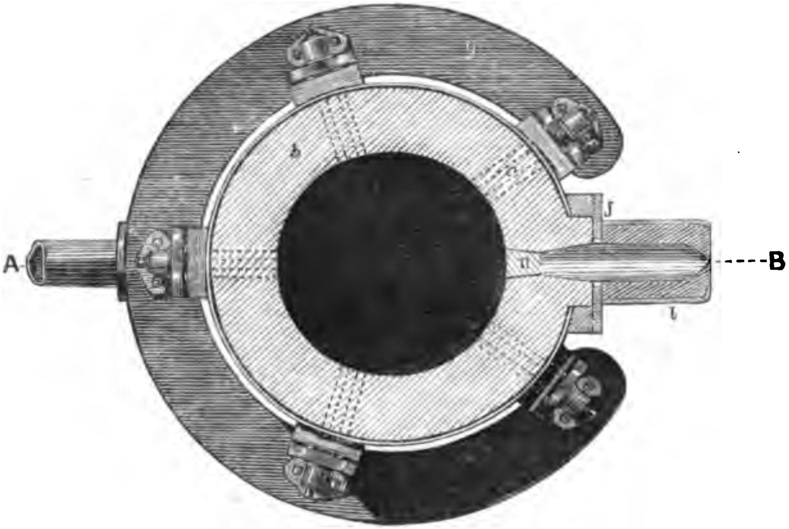
g

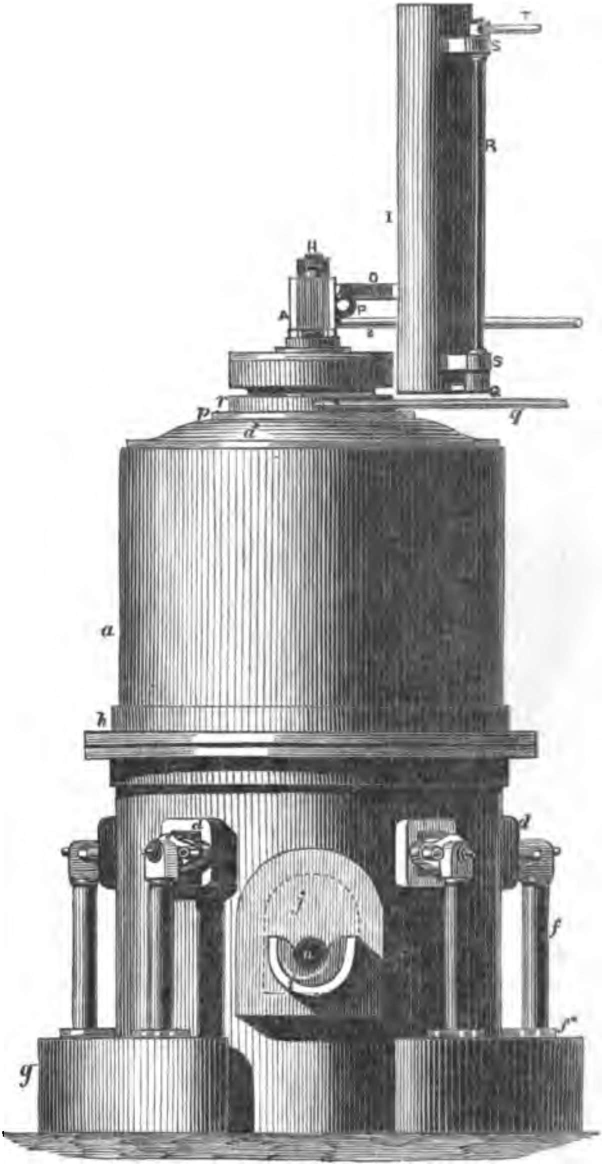
accessible. A small flange, *a*¹, prevents the brick-work of the upper part from being displaced when lifted off. The furnace is provided with a spout, *i*, lined with loam for conducting the metal into the casting ladle. A door, *j*, is formed at this part, having only a small opening in it. By unbolting the door and removing part of the lining the furnace may be cleaned out, the lining being afterwards made up as in ordinary cupola furnaces, or a conical piece of fire-brick, as shown at *n*, may be inserted, so that when the metal is to be drawn off from the furnace the workmen, instead of having to drive a hole through the solid material with a pointed bar, will simply drive the cone, *n*, into the furnace, and thus open a passage at once equal to the size of piece attached. A small cross bar and screw may be employed to prevent the accidental blowing-out of the cone, the bar extending across the door, *j*, and the screw pressing against the small end of the cone, *n*.

FIG. 126.



In order to secure the feeding door against a leakage of the products of combustion and against the force tending to

FIG. 127.



force it open, on the upper or crown plate or dome, *a**, of the furnace is riveted a stout ring of iron, *p*, around which a hoop, *r*, is tightly shrunk on, leaving a space or annular channel, s, in which water circulates, for the purpose of keeping it cool. The water is supplied by the pipe, *o*, and after circulating round the ring, *p*, it escapes by the pipe, *q*; the ring, *p*, is also further protected by the lining of the furnace, as shown at *b**.

FIG. 129.

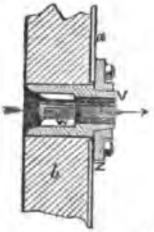


FIG. 128.

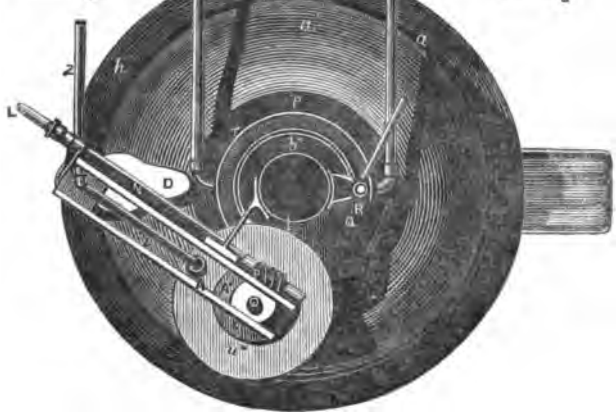
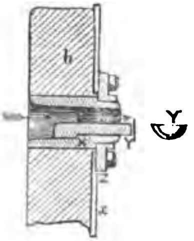


FIG. 130.



The frame, *u*, has a channel, *x*, formed around its exterior surface, over which a hoop of iron, *w*, is shrunk, so as to complete the annular passage, *x*. The lower surface of the frame, *u*, rests on the upper surface of the ring, *p*. The under-side of the frame, *u*, has a small V-shaped groove turned in it, and at about an inch apart all round this groove small holes are drilled, which pass upward at an angle and connect the V-shaped grooved channel with the annular space, *x*. A pipe, 2*, conducts air from the main blast pipe into the channel, *x*, which passes thence down the numerous small drilled channels, and thus supplies air under pressure to the V-shaped groove before named. Now the pressure of the blast exceeds the pressure of the gases within the furnace; consequently, any imperfection in the fitting of the door-frame, *u*, down upon the upper ring, *p*, of the furnace, instead of allowing the highly-heated gases to escape and act destructively on the metal fittings, such gases are prevented from escaping, because, in case of imperfect fitting of the metallic surfaces, the air under pressure in the V-shaped groove will, by reason of its superior pressure, force its way between the imperfect joint, partly escaping in the upper part of the furnace and partly into the external atmosphere.

In order to remove the door, *u*, from the mouth of the furnace, and readily replace it as required, a sort of crane arm is employed, consisting of two stout plate iron cheeks, A, A, bolted to the crane post, B; this latter is supported at its lower end in a socket, C, bolted to the angle flange, *h*. The upper end of the crane post is supported by a strong bracket, D, having a hole through it, in which the crane post turns; at E is a movable collar fitting into a journal formed on the crane post for the purpose of preventing the crane post from lifting upward when pressure is applied to the furnace door; between the cheeks, A, a piece of iron, A*, is firmly bolted, having a slot in the centre, in which a worm wheel, G, is fitted. This wheel and its elongated bosses, G*, form also a screw nut, through which the screw, H, works, a square part, H*, being formed on the upper end of the screw, to prevent its turning round, but not preventing its free motion upward or downward through the block of iron, A*, the holes in which are of a diameter equal to the largest diameter of the screw, and have no internal threads formed in them, the holes merely acting as guides for the screw, H, which carries on its lower end a plate fitting loosely inside a flanged ring, K, which is secured by bolts to the upper plate of the furnace door. The object of the ring, K, and the loosely fitting plate is to cause the door when lifted to be suspended in a horizontal position. The freedom thus given to the door is for the purpose of allowing it always to find its proper bearing on the ring, *p*, the end of the screw, H, then coming in contact with the upper plate, *u*, of the door will bind it firmly on its seat. For this purpose the handles, L, are mounted on the shaft, N, which also carries the worm, P; this worm gears into the worm wheel, G, by the rotation of which the screw, H, is made to rise and fall without rotation, carrying with it the door, *u*. Two stops may be used to prevent the crane arm from being moved too far in either direction.

For the introduction of fuel and metal into the furnace there is used a vertical feeding cylinder, I, made of thin plate iron, secured by a strong iron bracket, O, to the crane arm. The lower part of the cylinder, I, has a plate, Q (Fig. 127) fitted to it. The plate, Q, is keyed on to an upright spindle, R, supported by bearings, S, attached to the side of the cylinder, the upper end of the spindle having a handle, T, by means of which the plate, Q, is made to close or open the bottom end of the cylinder.

While the furnace is under blast, the workmen will put a charge of coke or other fuel into the cylinder, and along with it the scrap or other malleable metal to be fused, and when the cylinder is filled the blast may be turned off, the handles, L, put in motion, and the door, *u*, lifted sufficiently to allow the crane arm to be moved round until the feeding cylinder, I, is brought vertically over the mouth of the furnace. A slight movement of the handle, T, will remove the plate, G, from beneath the cylinder, and allow all the fuel and metal to fall at once into the furnace. The crane arm is then quickly moved back into its former position, and the door is again forced down by turning the handles. Immediately after the closing of the furnace the blast is turned on, and the operations of the furnace resumed, and at such intervals as is found necessary the same operation may be repeated. In the plan, Fig. 128, the crane arm is shown in the position it occupies during the time that the fuel is being discharged into the furnace. The plate, Q, is also shown removed from under it. Mr. Bessemer prefers to take the supply of air to the door, *u*, from the main blast pipe at a point where the equilibrium valve does not shut off the supply. The air will thus continue to flow during the time the fuel is being supplied to the furnace, and the act of moving the door again over its seat will cause the numerous jets of air from the small drilled passages before-named to blow away with considerable force all small particles of fuel or other matter from the surface against which the door fits.

In order to admit of the motion of the crane arm, and to continue the connection with the air supply, the pipe, 2, is taken to the top of the crane post, and is there jointed to the pipe, 2*; this piece of pipe, 2*, is made of thin copper or pewter, and will spring sufficiently to allow of the slight rise and fall of the furnace door. One of the chief peculiarities of this mode of working furnaces under a high pressure of the gaseous products within them, is the outlet for the escape of flame, so different to the ordinary cupola furnace, where the outlet is generally equal to the full diameter of the furnace. When working under pressure in one of these high-pressure furnaces, an opening of 2¼ inches in diameter has been found sufficient for a furnace whose transverse arc is 572 square inches, the outlet being about 144th part of the sectional area of the furnace. Thus it has been found that with an internal pressure of 16 lbs. to 18 lbs. per square inch in excess of the atmospheric pressure, 1 square inch area of outlet may be reckoned approximately as the area required for every 2 cwts. of coke burned per hour in such furnaces.

The outlet of the furnace at U, in its simplest form, consists of a square block of fire-brick, having a round hole in it of the desired size. It is made with a shoulder externally, which abuts against the interior of the casing, *a*, to prevent its being forced out by internal pressure; a slight difference in the area of the outlet materially affects the condition of the furnace. In Fig. 129 is a vertical section of the outlet block, V, having two internal diameters, forming a shoulder. Into this a small fire-clay cylinder, W, is put, for the purpose of contracting the area of outlet, and at Fig. 130 a similar outlet block is shown at X, having a small piece of moulded fire-brick, Y, inserted therein, and projecting sufficiently to be lifted out by a pair of tongs and be replaced by other pieces of different sizes. In both figures is shown a flange plate, *z*, by which the outlet blocks are retained in place. By unscrewing this flange plate, the outlet block, when too much worn, can be readily replaced by a new one.

The amount of pressure up to which the gaseous products are kept within the furnace will depend chiefly on the regulation of the pressure of the blast, the escape aperture being also regulated so as to prevent the pressure going below or getting above the point desired. In some cases the escape of the flame and heated matters may be regulated by a loaded valve, the face of which is formed of well-burned clay, in which case a stop may be provided, so as to prevent the valve from entirely closing.

There is also specified and illustrated, as before stated, a cupola movable on trunnions, but embodying a similar mode of constructing the outer shell of making and fixing the tuyeres, the crown and upper part and crane post, furnace door, and feeding cylinder.

The fuel used in these furnaces is preferably hard coke or anthracite coal, but combustible gases may also be used. The gas is generated in the ordinary way, and forced by a blowing engine into a gas receiver, where it is compressed. The form of furnace then used for melting steel and malleable iron by gas is the reverberatory, of brickwork, as usual, but enclosed in a strong iron casing, with a door on the plan described for the cupola. In the reverberatory form of furnace liquid, hydrocarbons can also be employed, either alone or with solid fuel. The liquid fuel is introduced into the blast pipe and taken in by the blast in the form of spray. The metal to be melted may be protected from undue oxidation by coating it with a mixture of clay, lime, and sand, with or without red ore or alkaline salts. Crucible furnaces on this system are made with a cylindrical fuel chamber, supplied with blast in the same manner as the cupola furnace, with a similar regulation for the pressure.

## ON LIQUID FUEL.

### By Benjamin H. Paul, Ph.D., F.C.S.*

Besides petroleum several other analogous materials have been proposed as substitutes for coal—for instance, the oil obtained by distilling particular kinds of coal, or the shale which occurs in coal formations, and more recently the oil known as "dead oil," which is one of the products obtained in rectifying the coal tar of gas-works. All these materials resemble each other closely in being composed chiefly of carbon and hydrogen, which are, in various proportions, the combustible and heat-producing constituents of all kinds of fuel. For the application of these materials and liquid fuel generally various methods have been proposed, but before speaking of them it is desirable to consider what is the evaporative power of these materials respectively, since that is a very important point to determine in regard to the question as to the relative merits of these different kinds of fuel.

The heat generated by combustion has been made the subject of the most careful investigation; and since the time of Lavoisier, Laplace, and Rumford the more precise measurement of the amounts of heat capable of being produced by the combustion of carbon and hydrogen has been repeated by several physicists with results which agree so closely that they may safely be regarded as well established. The names of Dulong, Despretz, Andrews, Favre, and Silbermann are, moreover, an unquestionable guarantee that these results, and the methods by which they were obtained, are perfectly trustworthy. According to these results the maximum heat-producing capabilities of carbon and hydrogen are in the ratio of 1 to 4·5. The actual quantities of heat generated by the combustion of a pound of carbon or of hydrogen are as follows:—

*Relative Calorific Power.*

| | Pound. | Heat Units. | |
|---|---|---|---|
| Carbon . . . | 1 | 14,500 | 1·00 |
| Hydrogen. . . | 1 | 62,032 | 4·28 |

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* Read before the Society of Arts, Wednesday, April 15th, 1868.

The heat unit here referred to is the quantity of heat which raises the temperature of 1 lb. of water 1° F. (from 40° to 41°). Therefore, the numbers given in the table represent the quantities of water capable of being heated 1° F. by the conversion of 1 lb. of carbon into carbonic acid gas, or of 1 lb. of hydrogen into water. As there are in the Fahrenheit thermometric scale 180° between the freezing point and boiling point of water, those numbers divided by 180 give the corresponding quantity of water capable of being heated from 32° to 212° F. Again, the quantity of heat required to convert a pound of water at 212° F. into steam of the same temperature is nearly five and a half (more exactly 5·37) times as much as that requisite to heat a pound of water from the freezing point to the boiling point; therefore, the quantities of steam capable of being produced from water at 212° F. by the total heat generated in the combustion of a pound of carbon or of hydrogen, are, of course, ascertainable by dividing the number of pounds heated from 32° to 212° F. by 5·37. These several quantities are given in the following table:—

| Quantities of Water | | | |
|---|---|---|---|
| Heated | | or converted into steam | by the heat generated in combustion of |
| From 40° to 41° F. lbs. | From 32° to 212° F. lbs. | From water at 212° F. lbs. | lb. |
| 14,500 | 80·55 | 15·0 | 1 carbon. |
| 62,032 | 344·62 | 64·2 | 1 hydrogen. |

These quantities of 15 lbs. and 64·2 lbs. of water convertible into steam by the total heat generated in the combustion of a pound of carbon or of hydrogen represent what is termed the "theoretical evaporative powers of those substances." By the term theoretical, however, it is not to be understood that these values are in any degree imaginary or assumed; they represent actual facts which have been established as the results of positive observation, and they are theoretical in reference to the practical application of fuel only in this sense, that these results are not realised in ordinary practice. The reason of this is not the existence of any uncertainty that the total quantities of heat generated by burning a pound of carbon or a pound of hydrogen are respectively capable of converting 15 lbs. and 64·2 lbs. of water at 212° F. into steam; but it is simply the fact that under ordinary circumstances only a portion of the total heat generated in either case is ever *available* for the production of steam. The statement of the theoretical evaporative power of fuel, or of carbon and hydrogen as constituents of fuel, is, therefore, like the statement of relative calorific power, only an expression of the relative capabilities, and it indicates in this respect a limit which, though it cannot be exceeded in any case, is never fully attained in practice.

In order to ascertain what portion of the heat resulting from the combustion of carbon and hydrogen is available for producing steam, it is necessary to consider what are the conditions under which fuel is usually burnt, and what becomes of the heat generated in the two cases. In making this inquiry it is also necessary to remember that the several substances concerned in the combustion of fuel require different quantities of heat to produce equal increments of temperature in equal weights, as stated in the following table:—

*Quantities of Heat.*

| One pound of | | Heat units. | |
|---|---|---|---|
| Carbonic acid gas | requires | 0·217 | To raise its temperature from T to T + 1° F. |
| Nitrogen | ,, . | 0·245 | |
| Atmospheric air | ,, . | 0·238 | |
| Steam | ,, . | 0·475 | |
| Water | ,, . | 1·000 | |
| Water at 212° F. | ,, | 966·100 | for conversion into steam. |

It will be seen that water has by far the greatest capacity for heat both in the state of liquid and vapour, and that a very large quantity of heat is rendered latent in the conversion of water into steam.

In the combustion of carbon each pound requires for its conversion into carbonic acid gas 2·67 lbs. of oxygen, which is derived from atmospheric air, and as this contains only 23 per cent by weight of oxygen it is necessary to supply about 12 lbs. (more accurately 11·61 lbs.) of air for every pound of carbon burnt.

In the combustion of hydrogen 8 lbs. of oxygen are requisite for each pound of hydrogen, and to furnish this about 35 lbs. (more accurately 34·78 lbs.) of air must be supplied.

But fuel is never burnt for raising steam in such a way that the supply of air is only just sufficient to furnish oxygen for the conversion of its carbon into carbonic acid gas, and of its hydrogen into water vapour. In order to maintain combustion it is necessary to remove the gaseous products from the furnace, as well as to supply fresh air continually; and when this is effected, as usual, by the draught of a chimney, the gaseous combustion products become mixed with the fresh air to some extent. The effect of this intermixture would be to retard the combustion of the fuel if the amount of burnt air or combustion products in the atmosphere of the furnace exceeded a certain proportion. Consequently, it is necessary to prevent this by supplying more air than would suffice to furnish oxygen for combustion, so as to dilute the combustion products and maintain an excess of oxygen in the atmosphere immediately surrounding the fuel in the furnace. Careful observation has shown that in ordinary boiler furnaces the quantity of air requisite for this purpose amounts to as much as that requisite for effecting the chemical change which takes place in combustion, so that the total supply of air to such a furnace is usually at the rate of about 24 lbs. per pound of carbon burnt, and about 70 lbs. per pound of hydrogen burnt.

Under ordinary circumstances, the relation between the quantities of these substances burnt as fuel, the total heat generated, the air supply requisite for supporting combustion, and the furnace gas resulting from it will be as follows:—

| Fuel. | Quantity burnt. lb. | Air supply. lbs. | Total heat generated. Heat units. | Furnace gas. lbs. |
|---|---|---|---|---|
| Carbon . . . . | 1 | 23·22 | 14,500 | 24·22 |
| Hydrogen . . | 1 | 69·56 | 62,032 | 70·56 |

The heat generated in either case is, at the moment of combustion, transferred to the gaseous combustion product, and raises its temperature. In the combustion of carbon the whole of the heat is effective in this way; but in the combustion of hydrogen a portion of the heat generated is consumed in determining the vaporous condition of the water produced in the proportion of 9 lbs. for each pound of hydrogen burnt. As 1 lb. of water at 212° F. requires 966·1 heat units to convert it into steam of the same temperature, the quantity of heat which becomes latent in this way amounts to 8694·9 heat units (9 × 966·1) per pound of hydrogen burnt, or 14 per cent of the total heat of combustion. That portion of the heat is ineffective either for increasing the temperature of the combustion product or for producing steam in the boiler, and it must therefore be deducted from the total heat generated in order to ascertain the amount of heat available, which is as follows, compared with that generated by the combustion of carbon:—

| | Quantity burnt. lb. | Total heat generated. Heat units. | Latent heat of water vapour produced. Heat units. | Available heat. Heat units. | Equivalent evaporation of water at 212° F. lbs. |
|---|---|---|---|---|---|
| Carbon . . | 1 | 14,500 | — | 14,500 | 15 |
| Hydrogen . | 1 | 62,032 | 8695 | 53,337 | 55 |

In the combustion of carbon, under the conditions above mentioned, the products constituting the furnace gas amount to nearly 25 lbs. per pound of carbon burnt, and they require the following quantities of heat to raise their temperature 1° of Fahrenheit's scale:—

| | Pounds. | | Specific heat. Heat units. | | Heat units. |
|---|---|---|---|---|---|
| Carbonic acid gas . . . . | 3·67 | × | 0·217 | = | 0·79639 |
| Nitrogen . . . . . . . . | 8·94 | × | 0·245 | = | 2·19030 |
| Surplus air . . . . . . . | 11·61 | × | 0·238 | = | 2·76318 |
| | 24·22 | | | | 5·74987 |

The increase of temperature resulting from the combustion of carbon is, therefore, found by dividing the number of heat units representing the total quantity of heat generated by the number of heat units requisite to raise the temperature of these combustion products, &c., 1°, and it amounts to—

$$2522^\circ \text{ F.} = \frac{14{,}500}{5{\cdot}75}$$

In the combustion of hydrogen under the same conditions the products constituting the furnace gas amount to about 70 lbs. per pound of hydrogen burnt, and they require the following quantities of heat to raise their temperature 1° of Fahrenheit's scale :—

|  | Pounds. |  | Specific heat. Heat units. |  | Heat units. |
|---|---|---|---|---|---|
| Water vapour . . . . . . | 9·00 | × | 0·475 | = | 4·27500 |
| Nitrogen gas . . . . . . | 26·78 | × | 0·245 | = | 6·56110 |
| Surplus air . . . . . . . | 34·78 | × | 0·238 | = | 8·27764 |
|  | 70·76 |  |  |  | 19·11374 |

Consequently, the increase of temperature resulting from the combustion of hydrogen is :—

$$2791^\circ \text{ F.} = \frac{62{,}032 - 8695}{19{\cdot}114}$$

So far, therefore, as relates to increase of temperature, the effect produced by the combustion of hydrogen under these conditions is not much greater than that produced by the combustion of an equal weight of carbon, notwithstanding the great difference in the actual quantities of heat generated, as shown below :—

|  | lb. | Total heat generated. Heat units. | Available heat. Heat units. | Increase of temperature. |
|---|---|---|---|---|
| Carbon . . | 1 | 14,500 | 14,500 | 2522° F. |
| Hydrogen . | 1 | 62,032 | 53,337 | 2791° F. |

We have now to consider what portion of the *available* heat is under ordinary conditions, *effective* in producing steam. The heated furnace gas resulting from the combustion of the carbon or the hydrogen of fuel is the medium by which the heat generated is transferred to the water in the boiler; and if it could be managed that, between the moment of combustion and the time when the furnace gas resulting from it is discharged into the chimney, the whole of the available heat could be communicated to the water in the boiler, the evaporative effect realised might then be equal, or nearly equal, to the theoretical evaporative power of the fuel burnt. But this is never the case in ordinary practice.

The extent to which the available heat could in any case become effective in producing steam by direct transmission to the boiler must, of course, be limited by the temperature corresponding to the pressure at which steam is to be raised.

If that were 50 lbs. per square inch the furnace gas could not be cooled down below 360° F. before being discharged from the heating surface of the boiler into the chimney. The quantities of heat which would in such a case pass away in the furnace gas without being directly effective in producing steam in the boiler, would amount to 12 per cent in the combustion of carbon, and to 10·8 per cent in the combustion of hydrogen, as follows:—

| | Quantity burnt. | Furnace gas. | Quantity of heat requisite to produce increase of temperature = 300°. | Equivalent evaporation of water at 212° F. |
|---|---|---|---|---|
| | lb. | lbs. | Heat units. | lbs. |
| Carbon . . | 1 | 25 | 300° × 5·750 = 1725 | 1·8 |
| Hydrogen. . | 1 | 70 | 300° × 19·114 = 5734 | 5·9 |

These quantities of heat would therefore be wasted as regards the production of steam, except in so far as they might be applied in heating the feed water supplied to the boiler.

But when, as in ordinary practice, the supply of air for supporting combustion is maintained by the draught of a chimney, the temperature of the furnace gas cannot in any way be reduced below about 660° F. without interfering with the draught of the chimney, and thus a waste of heat is occasioned considerably larger than that just mentioned as being the minimum waste.

In very many instances the furnace gas is discharged into the chimney at a temperature very much more than 600° F. above the temperature of the external air, and then the waste of heat is of course even still greater in proportion as the temperature of the gas is higher.

In the case of furnace gas discharged at 600° F. above the temperature of the air supplied to the furnace, this waste amounts to 24 per cent of the available heat resulting from the combustion of carbon, and to 22 per cent of that resulting from the combustion of hydrogen, these amounts being equivalent to the evaporation of 3·6 lbs. of water at 212° F. per pound of carbon burnt, and to 11·9 lbs. of water at 212° F. per pound of hydrogen burnt.

The amount of heat capable of becoming effective in producing steam cannot, therefore, be greater than the difference

between the total available heat and
in the furnace gas. This amount is
the available heat generated by comb
about 78 per cent of that generated b
drogen. This comparison does not ta
sources of waste which are due to impe
applies only to such portions of the
of fuel as are actually burnt in the f
the comparative efficiency of these c
producing steam is as follows:—

*Combustion of Carbo*

| Quantity burnt, 1 lb. | Heat units |
|---|---|
| Total heat of combustion . | 14,500 |
| Available heat . . . . . | 14,500 |
| Waste heat of furnace gas . | 3,480 |
| Effective . . . . . . . . | 11,020 |

*Combustion of Hydro*

| Quantity burnt, 1 lb. | Heat units |
|---|---|
| Total heat of combustion . | 62,032 |
| Latent heat of water vapour. | 8,695 |
| Available heat . . . . . | 53,337 |
| Waste heat of furnace gas . | 11,520 |
| Effective heat . . . . . | 41,817 |

Thus the maximum evaporative effic
hydrogen is, for each pound burnt, resp
conversion of about 11½ lbs. and 43½ lb
into steam of the same temperatu
ordinary atmospheric pressure. The
*efficacy* is *realised* in the ordinary applic
ducing steam will depend upon the rela
by the rate of combustion and by the
boiler for the full absorption of the ef
combustion products during their pass
tubes of the boiler before being discharg

But whatever may be the influence of these conditions in regard to evaporative effect produced, they do not in any degree affect the foregoing considerations as to the maximum evaporative capabilities of the carbon and hydrogen of fuel when burnt in the manner stated, with a supply of air just twice as great as the quantity requisite for their conversion into carbonic acid gas and water vapour.

From these considerations it will be evident that, in the combustion of fuel under ordinary conditions, there is always a great waste of heat actually generated and available. The total waste is considerably greater in the combustion of hydrogen than it is in the combustion of carbon, amounting in the one case to 32·6 per cent, and in the other to 24 per cent of the total heat of combustion, but still the evaporative efficacy of hydrogen is nearly four times as great as that of carbon.

In the combustion of hydrocarbons under these conditions, whether they be solid, liquid, or gaseous, the total amount of heat generated will be determined by the relative proportions of the carbon and hydrogen they contain. The amount of hydrogen in such substances generally ranges from one-seventh to one-fourth by weight, and for such limits the corresponding amounts of heat generated by their combustion and their theoretical evaporative power would be as follows :—

| Hydrocarbon burnt. | Carbon. | Hydrogen. | Total heat of combustion. | Equivalent evaporation of water | |
|---|---|---|---|---|---|
| | | | | at 212°. | at 60°. |
| lb. | lb. | lb. | Heat units. | lbs. | lbs. |
| 1 | 0·86 | | × 14,500 = 12,470 | | |
| | | 0·14 | × 62,032 = 8,684 | | |
| | | | 21,154 | 21·9 | 18·8 |
| 1 | 0·75 | | × 14,500 = 10,775 | | |
| | | 0·25 | × 62,032 = 15,508 | | |
| | | | 26,283 | 27·1 | 23·3 |

It must be remembered that these results are above the truth, for this calculation does not take into account the quantity of heat expended in effecting the decomposition of the hydrocarbon, *i.e.*, the separation of the carbon from the hydrogen, nor does it make allowance for the circumstance maintained at the same rate, would have the effect of reducing the waste of heat to the extent of 50 per cent, and economising the heat generated by the carbon of the fuel to the extent of nearly 12 per cent. Herein consists the advantage gained by blowing the air into a furnace instead of drawing it in by means of a chimney, for in that case the supply of air may be reduced to just enough to support combustion, and at the same time the temperature of the furnace gas may be so far reduced, either within the flues or tubes of the boiler or in a feed-water heater, as to render the greater part of the heat contained in it effective for production of steam.

The possibility of economising in this way the heat generated by combustion of carbon is by no means unimportant; but it is of far greater importance as regards the heat generated by combustion of hydrogen, for in that case the total waste of heat arising from the discharge of the furnace gas at 600° F. above the temperature of the air supply is equivalent to about 12 lbs. of steam per pound of hydrogen burnt, and nearly one-half of this waste heat is consumed in heating the surplus air supply.

Therefore, by dispensing with this surplus air and cooling the furnace gas in a feed-water heater, a saving of something like one-fourth of the total available heat might be effected. A further advantage would also result from the increased temperature of combustion, viz., 4692° F. for carbon and 4922° F. for hydrogen, and the consequent more ready transmission of heat from the combustion product to the water in the boiler:—

*Combustion of Hydrogen.*

| | Furnace gas from 1 lb. hydrogen. lbs. | Quantities of heat in furnace gas. Heat units. | Equivalent evaporation of water at 212° F. lbs. |
|---|---|---|---|
| Water vapour . | 9·00 | 600° × 4·3 = 2580 | 2·7 |
| Nitrogen gas . . | 26·78 | 600° × 6·6 = 3960 | 4·1 |
| Surplus air . . | 34·78 | 600° × 8·3 = 4980 | 5·1 |
| | 70·56 | 11,520 | 11·9 |
| Latent heat of water vapour | | 8695 | 9·0 |
| | | 20,215 | 20·9 |

The combustion of the carbon and h
sents another point of difference, wh
regards the extent to which the avai
ordinary conditions, capable of being
producing steam. This difference is d
water vapour in the furnace gas, resulti
tion of hydrogen. As a consequence of
large amount of heat is absorbed and
for producing steam. From the foregoi
the disposition of heat amongst the fu
seen that every pound of water vapour
corresponds to a waste of heat sufficie
more than 1¼ lbs. of steam, and hence i
great is the disadvantage resulting fr
water in the furnace gas, whether origin
burnt or from damp fuel or otherwise.

The volumes of the air supply and
for the extreme cases of carbon a
follows :—

| | Air supply at 60° F. | | |
|---|---|---|---|
| | lb. | lbs. | cubic feet |
| Carbon . . | 1 | 24 | 320 |
| Hydrogen . | 1 | 69 | 960 |

In the combustion of carbon there
volume in the combustion product, exc
heat generated, which would render
temperature of combustion (2522° F.)
six times that of the air supplied. By t
to the boiler to such an extent as to red
to 660° F. the volume would be redu
630 cubic feet per pound of carbon burn

In the combustion of hydrogen the su
is about three times as large as that
bustion of an equal weight of carbon.
pansion of the combustion products, ind
generated, and amounting to one-half t
the hydrogen burnt. The expansion
greater than in the combustion of carbo

greater amount of heat generated, so that the volume of the furnace gas at the temperature of combustion (2791° F.) would be about six and a-half times that of the air supplied, and the volume of gas discharged into the chimney would be about three and a-half times as great as in the combustion of an equal weight of carbon. This larger quantity of gas will, however, contain nearly four times as much effective heat as that resulting from the combustion of an equal weight of carbon, and its temperature will be about 270° higher, so that in this respect the use of fuel containing a large amount of hydrogen, provided it can be perfectly and readily burnt, presents an advantage as compared with fuel consisting almost entirely of carbon. Rather more than one-fourth of a pound of hydrogen would give as much effective heat as one pound of carbon with a somewhat smaller volume of combustion products. The extent to which this advantage affects the value or efficiency of fuel will, of course, depend on the amount of hydrogen it contains. Since no hydrocarbon available as fuel contains more than 15 per cent of hydrogen, the actual evaporative efficacy of such a material, when used under the ordinary conditions, cannot, at the utmost, be more than about 40 per cent greater than that of an equal weight of carbon. This, assuming it to be perfectly burnt, and the arrangement of boiler flues or tubes, &c., to be favourable for the transfer of heat, is the maximum effect to be looked for according to the data already given.

The amount of hydrogen in petroleum is probably larger than in any of the other hydrocarbons proposed to be used as fuel, and that contains, on the average, about 13 per cent. In coal and shale oil the amount of hydrogen is less. Consequently, the evaporative efficacy of these materials, as compared with carbon, would not reach the above limit of 40 per cent in excess. The ratio between these materials and ordinarily good coal is much about the same in regard to evaporative efficacy, since the hydrogen contained in coal compensates for the oxygen and ash it contains, unless the amount of these is very considerable.

The tables on pp. 766 and 767 show the relation between the

total heat of combustion and the
carbons, containing respectively 14
gen, as the amounts of heat consu
and the mode in which it is dispose

I am not aware of any liquid h
fuel which contains so much as 25
that an evaporative effect of about 1
of hydrocarbon burnt must be reg
result to be attained with such m
burning these hydrocarbons with
combustion, or half the quantities a
the above estimations, the effect c
would be from 13 per cent to 14 pe
case stated above, or about 18 lb
hydrocarbon, containing 14 per cent t

The plan of using liquid fuel, wh
has proved the most advantageous, i
extent, at any rate, secure the ac
forcing air into the furnace. Acco
is supplied to the furnace through
with a jet of high-pressure steam,
into spray, much in the same ma
as the perfume vapouriser—a liqui
by a current of air. The steam jet
a current of air which mixes with t
its combustion. This is the arra
Field and Aydon, and it appears to
effecting a very perfect combustio
have seen used in this way was th
which is a refuse product in the ref
sesses characters which render it r
leum or to the oil obtained by dist
for use as liquid fuel. In the first
greater than that of water—the
12 lbs.—it takes less space for st
coal oil, the gallon of which wei
8½ lbs. For the same reason it w
as the lighter oils in case of accide
on the surface of water and burning

Again, its very high boiling point, approaching to a red heat, and the great density of its vapour as compared with that of petroleum or coal oil, are great advantages as regards risk of explosion in consequence of the oil vapour becoming mixed with air and then catching fire. This could hardly take place with the dead oil except at a very high temperature, while petroleum readily gives off vapour to the air at a moderate degree of heat.

1 lb. of hydrocarbon, containing 14 per cent of hydrogen, yields about 31 lbs. of furnace gas, consisting of:—

| | Furnace gas. | Quantities of heat in furnace gas. | Equivalent evaporation of water | |
|---|---|---|---|---|
| | | | at 212°. | at 60°. |
| | lbs. | Heat units. | lbs. | lbs. |
| Carbonic acid | 3·16 | 411 | | |
| Water vapour | 1·26 | 359 | | |
| Nitrogen gas. | 11·45 | 1683 | | |
| Surplus air | 14·37 | 2124 | 2·2 | |
| | 30·74 | 4577 | 4·8 | |
| Total heat of combustion | | 21,154 | | |
| Latent heat of water vapour | | 1217 | 1·3 | |
| Available heat | | 12,937 | | |
| Waste heat of furnace gas | | 4577 | 4·8 | |
| Effective heat | | 15,360 | 15·8 | 13·6 |
| Theoretical evaporative power | | | 21·9 | |

Relative evaporative efficacy as compared with carbon or coal = 1 . . . . . . 1·36

1 lb of hydrocarbon, containing 25 per cent of hydrogen, yields about 36 lbs. of furnace gas, containing:—

| | Quantities. | Quantities of heat in furnace gas. | Equivalent evaporation of water | |
|---|---|---|---|---|
| | | | at 212°. | at 60°. |
| | lbs. | Heat units. | lbs. | |
| Carbonic acid gas | 2·75 | 358 | | |
| Water vapour | 2·25 | 641 | | |
| Nitrogen | 13·39 | 1968 | | |
| Surplus air | 17·39 | 2483 | 2·6 | |
| | 35·78 | 5450 | 5·6 | |

would be of little account if it be not supported by adequate evidence of results, such as those which have been so much dwelt upon, being really obtainable; and although this subject has now been some years before the public, I am not aware of any evidence having yet been brought forward such as would call for or justify the abandonment of those well-established principles by which the heating power and efficacy of fuel is determined as above stated.*

The results of the experiments made at Woolwich under the superintendence of Mr. Tricket, the engineer-in-chief of the dockyard, give as the highest evaporative effect obtained with petroleum, 11·63 lbs. of water converted into steam per pound of oil burnt. In this case, however the combustion was imperfect. But in the most successful trials with coal oil and shale oil, when very little smoke was given off, the evaporative effect was about 18 lbs. of steam produced per pound of oil burnt. In this case some deduction required to be made for the steam applied as a blast to the fire, but the amount was not ascertained. This result was also obtained under peculiarly favourable circumstances as regards the proportion of heating surface of the boiler to the rate of evaporation.

In regard to the supply of material capable of being used as liquid fuel, it is necessary to make a few remarks. First, as regards petroleum, I imagine it is now generally acknowledged that this material in its natural state is not well adapted for the purpose. In that state it contains a large amount of very volatile hydrocarbon, which, even at the ordinary temperature, vapourises by contact with air, and

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* Since writing this paper I have learnt that the same subject was discussed by Professor W. J. M. Rankine, at the United Service Institution, about a year ago, and I have great pleasure in referring to the opinions of such an authority in confirmation of the views I have expressed in regard to "Liquid Fuel," "On the Economy of Fuel, Comprising Mineral Oils," "Journal of the United Service Institution," xi., 218. The very lucid and exhaustive exposition given by Professor Rankine, of the conditions which determine the theoretical evaporative power of fuel ought to have been sufficient to prevent any continuance of misconceptions as to the possibility that the evaporative effects realised with fuel can exceed or even equal the extreme calculated power it is capable of producing.

the mixture of this vapour with a
to remove this objection to the u
fuel, the more volatile portion of
distillation, and that operation, wh
render the oil fit for use with s
quantity to about one-third.

Another objection to petroleum i
bulkiness, the gallon weighing only
some extent removed by the distill
tion of the quantity to one-third,
weighs about 8 lbs. per gallon.

According to the latest returns
petroleum in America—which is o
most abundant source of this mat
360,000 tons a year. It would be
any opinion as to whether this ra
maximum which is attainable or as
tinue; but the prevailing impress
from which this supply originates a
lations, and therefore not to be depe
limit. The experience of oil winni
firmed this view, for it has been fou
were at first what are termed "flowi
their oil spontaneously, have gradua
that after pumping has been resorte
to the surface, even that means g
effect. It would therefore be un
supply of petroleum as affording ma

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## ON THE PURIFICATION OF TIN O

By Robert Oxland,

Tin ores are rarely found associated
this association does occur, the pr
frequently very large. It cannot be
oxide by the ordinary processes of cal

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* Chemical News, vol. xix., p. 251.

water, be

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of the wolfram by making the tungstic acid combine with the soda; at the same time to convert the basic protoxides of iron and manganese into peroxides, for the purpose of rendering them as light as possible to facilitate their subsequent separation by mechanical washing. This calcining operation is therefore essentially an oxidising one, and the fire should be worked accordingly. The charge drawn from the furnace should not cake. While hot it is thrown into one of a series of lixiviating cisterns partially filled with water, which is thereby rendered boiling hot. After standing a short time the liquor is run slowly off from the bottom of the vat bright and clear, and, if of sufficient strength, is set aside to crystallise; otherwise it is boiled up to strength before it is put into the crystallisers. The weaker liquors are used instead of water for lixiviating fresh charges of the calcined ore. Traces only of stannate of soda are to be found in the liquor if the operation be properly conducted.

Salt cake may be advantageously employed when skilled labour is obtainable; it is mixed with the ore in proportions indicated by the quantity of wolfram present. A quantity of coal-dust slightly in excess of the quantity necessary for the deoxidation of the sulphuric acid of the salt cake, is mixed with the charge, and the whole is exposed until red-hot in the furnace to the deoxidising flame. After this a clear fire and an oxidising flame are maintained until the tungstic acid has, by combination with the sodium, driven off the remainder of the sulphur. The charge takes about an hour longer in the furnace than is necessary for the soda ash mixture.

The charge drawn from the furnace is lixiviated in the same manner as before, and after all the soluble matter has been removed, the remainder of the charge is thrown out from the vats and subjected to a series of washing operations without any stamping, but occasionally with a small amount of scrubbing, whereby the peroxides of iron and manganese are washed off. The last traces of these oxides may be removed by digestion for a few hours in muriatic acid, leaving the binoxide of tin, or black tin of the Cornish miner, nearly pure, capable of producing, by smelting, the finest quality of metallic tin.

By A. GIRAUD.[*]

In my improvements in separating silver from argentiferous lead, in purifying lead, and in the necessary apparatus, I commence with extracting as completely as possible by any of the ordinary methods the antimony which may be contained in the lead. Immediately afterwards I place the lead in any suitable vessel, but by preference I employ for this purpose a melting pan (hereinafter called boiler), to which I adapt an opening at its base in order to allow the fused metal to be run off as required. This melting pan or boiler may be set on an ordinary furnace, but by preference the furnace should be provided with a movable grate, which will facilitate the instantaneous extinction of the fire.

For greater clearness in my description I shall divide my boilers, composing each range into the following order; that is to say:—First boiler containing the argentiferous lead freed from antimony; second boiler reserved for the rich litharge or dross; and third boiler for the extra rich skimmings of the litharge or dross. Although I here mention three boilers for the purpose of exemplifying my process, I do not limit myself to that number. I light up the furnace of the first boiler, and when the lead therein is reduced to a perfect state of fusion, I increase the intensity of the fire, and then I add to the fused metal a sufficient quantity of zinc, the proportion varying according to the richness of the lead, previously ascertained by assay. I immerse the zinc by means of an apparatus next hereinafter described, and which I call a "mixer." This apparatus consists of a box or case divided into two parts, united by bolts or otherwise. The box or case is perforated and attached to a metallic spindle, provided with radiating branches or paddles to promote the mixture of the zinc with the fused metal. But I do not confine the arrangement of vanes or paddles to the simple disposition of projecting or horizontal arms or branches; any system of horizontal or vertical vanes or paddles working from or in combination with the spindle and box or receptacle, and conveying thither the oxide of zinc and other matters. This chamber should be divided into several compartments and conveniently ventilated. The steam pipe is sunk in the molten metal to such a depth that the steam may spread throughout the mass of metal. If the boiler be very large, and one jet of steam insufficient to reach the zinc in every part, the principal pipe may be fitted with several auxiliary pipes, which will permit the steam to penetrate quite through the molten lead. The higher the temperature of the steam the more prompt and efficacious will be its effect. It will be prudent to adapt to the steam pipe externally two taps ; one for regulating the admission of steam into the metal, the other to be first opened to let off any water collected in the pipe, which will prevent any spattering of the fused metal. I do not restrict myself to the use of taps ; any other available means of regulating the passage of the steam, and for drawing off the moisture and precluding condensation, may be employed. When the steam shall have been introduced into the molten lead, it will be desirable to ascertain when the oxidation is completely terminated. To that end a valve or tap, or other contrivance of the kind with any suitable appliances, is fitted to the escape tube, to permit of seeing whether the steam passes in its natural state clear of oxides or other matter, and then, its function being terminated, the steam is suppressed. The cover with its appliances is then removed, and all the oxides and other matters which float on the surface are very lightly skimmed off, carefully avoiding the metal as much as possible. Now that the lead is entirely purified it is poured in the usual way, or run out into moulds in the shape of pigs or ingots, or otherwise. If the latter operation be employed, the conduit by which the lead is run off should be heated by an appliance in the nature of a chafing dish or brazier, or otherwise, for the purpose of preventing premature cooling. For conveyance of the moulds, and in order to expedite that operation, I employ by preference, but not exclusively, a rail or tramway with appliances for transmission, which I call port moulds, or little trucks.

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[*] Mining Journal, June 26, 1869.

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very small and nearly insignificant portion of silver, so small, in fact, that it may be disregarded. Then the contents of this boiler is re-heated to fusion with a brisk fire, and the lead is purified by the aid of one or more jets of steam, cleared of oxide, and skimmed, and the remaining metal is subsequently poured or run into moulds. As to the extra rich litharge or dross placed in the third boiler, when a sufficient quantity is collected, it is reduced to a perfect state of fusion, and with the application of steam, in a manner similar to that hereinbefore described, it is freed from the zinc and other matters. Immediately after this operation the product may be taken to the cupel furnace, or otherwise disposed of, for the purpose of obtaining the silver in a state of purity by any approved method. By continuing these operations, employing small pots, by preference somewhat of the form of crucibles, and with the modifications in manipulation self-evident to a skilful workman, the silver may be freed from alloy or impurities, so that it may remain in a state of purity, or nearly so. When a sufficient quantity of oxide and other matters of a nature to be converted to useful purposes is collected, suitable means are adopted to utilise the same.

## M. BOUDCHEN'S APPARATUS FOR PERFORMING THE PATTINSON PROCESS.*

M. Boudchen has contrived a system of apparatus by which a great part of the work of Pattinsoning is performed by power, and this is at work at Rouen, at Stolberg, and at Holzappel. The leading principle is that, in place of lading out the crystals, these are kept in agitation, both to prevent their agglomeration and their entanglement of liquid rich lead, and the still fluid rich or silver-lead is drawn off from

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The Practical Mechanic's Journal (with drawings), Feb. 1, 1869.

the pan by an aperture at the bottom. The apparatus consists of three pans upon different levels so as to run from one to the other, or out upon the floor level of the shop. Many of these apparatus may be in one work.

For convenience of our description we will call the upper pan *d*, the lowermost *a*, and that standing between, *c*.

*a* is the cylindric crystallising pan; the ingot moulds into which the rich lead is run through the spouts stand at either side of *a*, which are provided with iron sluice stoppers. *c* is the pan in which the raw pig lead is melted, and whence it runs into *a*; the latter pan being heated by the spare heat from the furnace of *c*. *d* is used as either a sort of magazine for *c*, which is supplied by a movable shoot, or from which the contents can be run into the ingot moulds, or to re-melt together different masses of the poor lead. This upper pan is not indispensable, and, in fact, is not used at either Holzappel or Rouen. Where the pan, *d*, is used the capacity of *c* is one-third, and *d* two-thirds of the pan *a*, but, as worked at Rouen, the pans, *c* and *a*, are of equal capacity.

The pan, *a*, is cylindrical, and contains two independent agitators or stirrers, driving (like brewers' mashing apparatus) through each other; the one being a system of blades or rakes attached to a rectangular frame driven by the outer or tubular shaft, and the other system of rakes like those of a pug mill nearly, driven by a central shaft, within the latter; and the two systems are driven reverse to each other. The pan is covered by a sliding-up and down iron hood, with two tubes, in connection with the chimney to take off lead fume.

When the crystals first begin to form it needs but little power to keep the whole mass in agitation; but as these increase in volume the resistance rapidly augments, and at last, with a proportion of two-thirds crystals and one-third fluid lead, from five to six horse-power is only sufficient to keep up the motion until after the rich lead has been run off. The heat is then augmented under *a*, and the crystals themselves become liquid, and are in turn run out, or, as is the better practice, they are rendered fluid by running in upon them a fresh charge of liquid raw lead from the pan, *c*, continuing this ment.

M. Gruner states that with each 9-ton pan, and with nine horse power, from 110 to 120 tons of lead can be refined per month, the merchant pig, or impoverished lead, being brought to about 20 grammes of silver per ton, and the silver-lead brought up to from 15 to 20,000 grammes per ton; the total consumption of fuel, including that for power, reaching to 1 ton of coal for 4 of lead refined.

The cost of labour is reduced to about one-half, and the hand-work that remains to be done is less laborious, more wholesome, and less subject to the caprice or neglect of the men, and there is less rich dross produced, because the covered pans enable the work to be conducted in great part in an atmosphere of lead vapour; against all this, however, is the greater capital invested, the excess on one set of pans being, probably, from £700 to £800. The total saving over the ordinary methods is stated to amount to about 18s. per ton of lead.

## THE EXTRACTION OF SILVER FROM RICH LEAD BY MEANS OF ZINC.*

In the opinion of Gruner, every system of Pattinsoning is likely to be ultimately superseded by Parkes's method of refining—by alloying the crude lead with zinc. The process, of which the following is a sketch, is one of singular beauty at every stage. It is based upon the curious relations which lead and zinc, and zinc and silver, bear to each other when alloyed, and to the facilities with which zinc and silver are separable by divers methods:—

Karsten, in 1842, had observed the reciprocal chemical actions of lead and zinc. He had ascertained that the two metals will not combine as alloys with each other better than do lead and copper. When the mixture of the two metals in a melted state is kept at rest, the zinc comes to the surface, retaining scarcely 2 per cent of lead, whilst the repose. It has further been ascertained that the lead often takes up between ¾ and 1 per cent of zinc, and that without regard to the total proportion of zinc mixed, so that 4, 5, or 20 per cent gives the same final alloy. The temperature of fusion, also, is without any influence on the result. The stirring was produced in a mechanical manner, as in the Laveyssière's system above described. No great power is here required, as the two metals remain in a fluid state, and only oxidated drosses are produced. The zinc tending to oxidate most, the oxygen does not act upon the lead, and there is a defective reaction. This could be avoided in two different ways; the zinc might ascend drop by drop through the lead, or else the lead might be made to descend drop by drop through the zinc. The first, the more efficacious of the two, appeared to Karsten difficult to carry out. He therefore applied the second, which had already been used in the process by which cupreous materials had been unsilvered, by the method known as that of *imbibition*.

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* Practical Mechanic's Journal (with drawings), Feb. 1, 1869.

The raw lead was passed through an iron sieve into a pan which contained melted zinc. After three hours of rest, without any rake agitation, the lead was racked off through an iron pipe at the bottom of the pan; the disargentation was complete. Upon the same zinc was poured a fresh quantity of lead, and it was operated upon in a similar manner. The content in silver could thus be brought to 25 per cent, always with the use of the same zinc, and without reducing the completeness of the impoverishment of the lead. The lowest strata of the lead contained only ¼ per cent of zinc, the highest ones about 1 per cent.

The argentiferous zinc which was thus obtained was then distilled in a Silesian muffle. The silver remained with the lead which was mixed with the zinc in the triple alloy. Operating upon 200 kilos. of the triple alloy, there were 120 kilos. of raw lead to 1½ per cent of silver, which was treated by direct cupellation to isolate the silver. As regards the expense, it was found that this process of disargentation costs only one-third of that of the old-fashioned direct cupellation in mass. The latter costs 35 francs 50 cent. for the ton of raw lead, without including general expenses, but taking into account 4½ per cent of loss upon the lead. Disargentation by zinc thus costs 10 francs 50 cent., or about 12 francs, including the expense of distillation of the zinc, the cupellation of the rich lead, and the maintenance of the implements and apparatus. The expenditure of the zinc process is composed, in reality, of the following details :—

| | Francs. |
|---|---|
| Wages to Workmen . . . . . . . . | 1·30 |
| Coal . . . . . . . . . . . . . . | 3·00 |
| 5 kilos. of waste in the lead . . . . | 2·25 |
| 5 kilos. loss on the zinc . . . . . . | 1·85 |
| 7·50 grammes loss on the silver . . . | 1·65 |
| Total . . . . . . . . . . . | 10·05 |

Notwithstanding this evident advantage, they did not venture in 1852 to adopt the new process at Tarnowitz. They feared not to be able to deprive the lead itself, in a convenient manner, of the small residual amount of zinc. They confined themselves to experiments for its purification by means of a prolonged re-melting of the lead, with long repose. Karsten, however, in the end, did advise the practical use of zinc, and expressed his opinion that the lead could be purified, by means of oxidation, on the hearth of a reverberatory furnace. These previsions of Karsten have been realised. The zinc refining of the raw lead is applied at the present time, not only in England, but also in Germany and in France; and it is found easy to separate now, either by oxidation or by chlorinisation, all the zinc from the disargentated or poor lead, so as to render it fit for commerce. Comparing the sum of 10·05 francs, or even of 12 francs, with the prime cost of the Pattinson process, it will be seen that the zinc refining has the advantage. The loss on the lead, which amounts to 2 per cent in the Pattinsonising, properly speaking, is in this case reduced to one-half, or to 1 per cent. If we add to that the advantage of less extensive works and of a much quicker mode of operating, we arrive at a reduction both of the capital invested in the establishment and the floating capital needed to carry it on.

This disargentation by zinc is in use in Wales; in Germany, at the works at Mechernich, near Commorn, and at Braubach on the Rhine; in France, at La Pise, and at the refining works of M.M. de Rothschild, at Havre. (Parkes's process has lately been adopted in many other works besides; for instance, in the lead works of the Hartz.) At Braubach, in place of driving off the zinc from the silver by volatilisation, as they do at Tarnowitz, and as is done in Wales, they separate it in a very ingenious way. From lead drosses or chimney fumes they obtain chloride of lead, by direct treatment with dilute hydrochloric acid, an educt of chemical works. This chloride of lead is agitated in a cast-iron pan, with the rich silver zinc at a low red heat; chloride of zinc is formed, and the lead set free, which is then separated from the silver by cupellation. The poor lead again is deprived of its small content of zinc, by treating it in like manner with chloride of lead. The chloride of zinc is treated in reverberatory furnaces, in order to extract any remains of lead mechanically mixed with it. It would seem to us better practice to lixiviate and wash out the lead, and to concentrate the chloride of zinc, for which a market might be found as a vegetable preservative and disinfectant.

Gruner gives his own preference to the steam oxidation process for getting rid of the zinc, rather than to the treatment by chloride of lead, as being more efficacious, less unwholesome, and less costly.

## SPENCE'S PROCESS FOR CALCINING COPPER AND OTHER ORES.

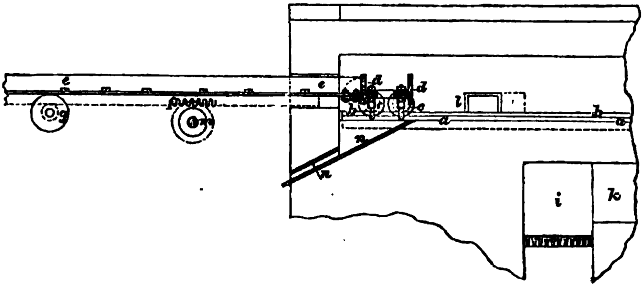
Patented January 7th, 1868.

MR. PETER SPENCE's improvement of his roasting furnace described in vol. ii., p. 152, consists in the use of instruments or rakes which travel in the furnace to stir the material, and also to bring it gradually forward to the end at which it is discharged. Any other furnace, in which the heat is admitted to a chamber beneath the ores, may be likewise used.

The raking machinery is applicable to all compounds containing sulphur, if in a small or powdered form, such as mundic, copper ores, zinc ores, and some artificial compounds containing sulphur, and which are difficult to work by hand stirring. It gives almost perfect immunity from dependence upon the carefulness of workmen, and with mechanical charging of the furnaces independence of the workmen would be perfectly realised.

The raking machinery is perfectly successful in actual working, each engine at present working two furnaces with a very small expenditure of steam, and giving very regular results, with a loss on the average of under 3 per cent of all the sulphur contained in the ores operated upon, each engine effecting a saving in actual labour expense of £120 per annum.

FIG. 133.

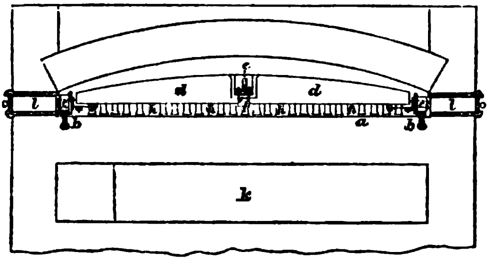


The patent is numbered 64, and we cannot better describe the principle of the process than by using Mr. Spence's own words, quoted from the specification:—

"Fig. 133, represents in longitudinal section a portion of a furnace with my improvement adapted, and Fig. 134 is a cross section thereof.

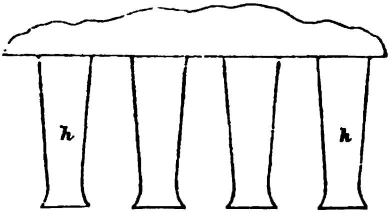
"The bed of the furnace is at *a*, in which are mounted two rails, *b*; upon these rails are wheels, *c*, mounted loosely upon axles which are attached to a frame, *d*; to this frame is bolted a bar, *e*, carrying on its under side a rack, *f*, and resting upon rollers, one of which is shown at *g*; but there are several placed at intervals, carried by any suitable bearings, the length of the bar, *e*, being such as not to pass off the innermost of the said rollers when the frame, *d*, is at the back end of the furnace. The frame, *d*, carries two rows of instruments, *h*, $h^1$, which project downward nearly to the bed of the furnace, and the two rows are so placed that an instrument in one row is opposite to a space in another; at Figs. 135 and 136 they are shown detached, the latter

FIG. 134.



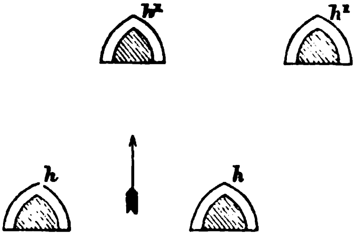
showing their horizontal section, and it will be seen that on one side they are pointed and on the other flat. At *i* is the fire-place, and at *k* the chamber, through which the products of combustion pass, and by means of which the furnace becomes heated. At *l* is one of a series of doors

FIG. 135.



extending at intervals along each side of the furnace, as described in the specifications of my former patents aforesaid, and at the front of the furnace is an inclined shute, *n*, through which the material passes when calcined. The ore having been first ground or otherwise brought into a state of fine division is fed across the furnace through one of the doors at the back thereof, and motion is communicated by means of the shaft and pinion, *m*, to the rack, *f*, whereby the frame, *d*, will be caused to advance towards the back of the furnace; the instruments, *h*, moving in the direction of the arrow, Fig. 136, the pointed parts will therefore advance through the material, and their curved bottoms, seen in Fig. 135, acting as ploughshares will stir and turn the material over. When the frame has reached the back of the furnace, the motion of the shaft, *m*, is reversed, and the frame, *d*, with its instruments, travels towards the front of the furnace, and the flat parts of the said instruments will now therefore act against the material, a portion of which will be carried forward. The frame, *d*, and its stirrers is now in a highly heated state, and in order to allow it to cool, the motion of the shaft, *m*, is arrested, so that the apparatus may remain stationary for a period, and as it is now over the shute, *n*, it receives the current of air passing through the same. When the desired cooling has been effected (say, in four or five minutes), the shaft, *m*, is again put in motion and the operations above described are repeated. The charge above described is repeated at the back end of the furnace about every hour, and I find the said charge may be about 1½ cwts. for a furnace 32 feet long and 6 feet wide, the speed of the rakes being about two minutes from the front of the furnace to the back and back again; and as the above-mentioned charging continually goes on for each said hour a portion of the material is carried forward each time by the flat part of the rakes, and is ultimately delivered through the shute, *n*; but as such portions are continually falling off the rakes, they are only carried forward through

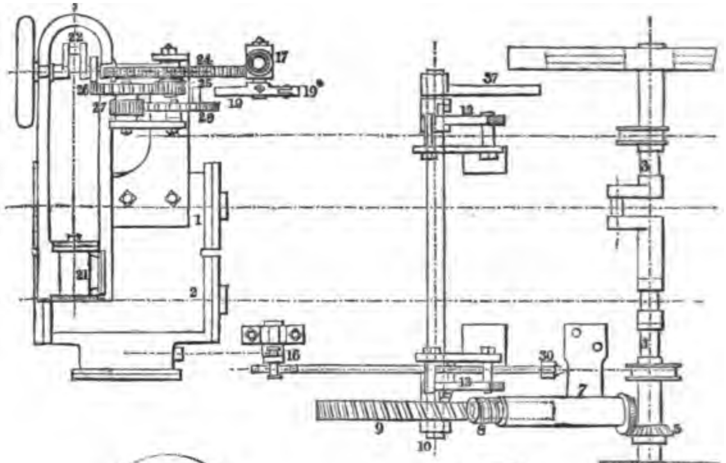
FIG. 136.



short spaces at each raking, and they therefore only gradually make their way to the delivery end.

"I have above described my invention so far as regards the

FIG. 137.



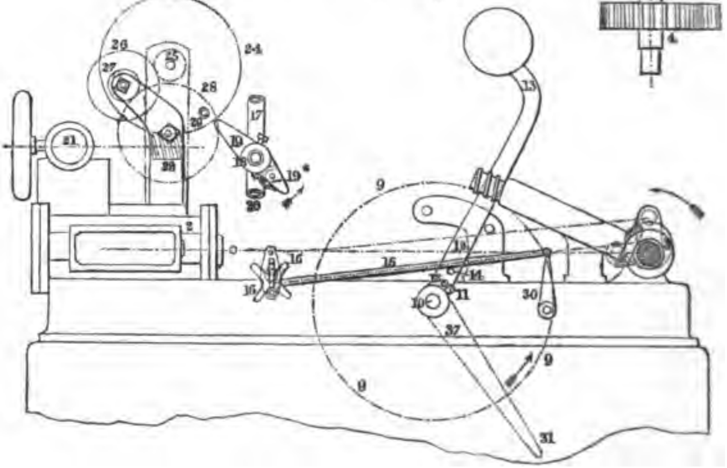


FIG. 138.

essential character thereof, namely, the method of stirring the material and of gradually bringing it to the delivery end of the furnace.

"The mechanical means of causing the forward and backward motion of the rakes may be varied to a considerable extent, as will be evident to all competent mechanics; but I will now point out an arrangement which I have had in use and have found to answer the purpose, referring for this purpose to Figs. 137 and 138, the former being a side view, and the latter a plan of a pair of engines and other parts which may be used separately for each furnace, or for two or more. At 1, 2, are two steam cylinders, communicating motion by their piston rods to the crank shaft, 3, upon which there is a pinion, 4, taking into a wheel, 4*, which is on the shaft, *m*, the same as that denoted by the same letter of reference in Fig. 133. Upon the crank shaft, 3, is a bevil, 5, taking into another, 6, upon a shaft mounted in a bearing, 7, and this shaft is provided with a worm, 8, in gear with a worm wheel, 9, mounted on a shaft, 10; on this shaft is a tappet, 11, which at intervals, as will be described, arrives in contact with a pin, 12, projecting from a lever, 13, turning loosely upon the shaft, 10, and the said lever, 13, also carries another projecting pin, 14, situate beneath the ordinary excentric rod, 15, which at its end is connected to the valve rod by the usual gab motion, 16. The steam pipe for the cylinders is, at 17, provided with a stop tap, 18, upon which is mounted a lever, 19, 19*, the end, 19*, thereof being pressed in the direction of the arrow by a spring, 20, and the said end, 19*, is jointed so as to be capable of turning against the force of the said spring in one direction. Adjoining the steam cylinders, 1, 2, is a supplementary small steam cylinder, 21, the piston of which is constantly going and communicates motion to a crank, 22, on the shaft of which is a worm, 23, taking into a wheel, 24, which then drives the train of clockwork, 25, 26, 27, 28, on the last of which there is a projecting pin, 29, arriving at certain times in contact with the lever, 19. According to the positions of the parts shown, the rakes are proceeding from the front to the back of the furnace and have nearly reached that position, they having been driven forward by the wheel on the shaft, *m*. The tappet, 11, will therefore soon arrive in contact with the projecting pin, 12, and when that takes place the said lever will be turned over until the weight thereon has passed the vertical line, after which it will fall over and bring the pin, 14, to bear against the excentric rod, 15, which, by turning upon the rocking lever, 30, will shift the position of the gab motion, 16, and thus reverse the engines, there being a lever, 13, and pins, 12, 14, for each of the two driving steam cylinders; the driving wheels will now revolve in the contrary direction, and the rakes will travel back towards the front of the furnace, carrying with them, as before described, a portion of the material. When this has been effected, the lever, 31, on the shaft, 10 (and which is now moving in a direction contrary to the arrow), will arrive in contact with the lever, 19*, thereby causing the stop-tap, 18, to be turned and the steam to be shut off; the motive power being thus arrested, the rakes will remain at the front and colder end of the furnace a sufficient time to cool, and that period is determined in the following manner:—It has been stated that the small cylinder, 21, is constantly supplied with steam, and the train of gearing, 23 to 28, is therefore constantly revolving, and the numbers of teeth are so arranged that when the rakes have been allowed to remain stationary a certain time, a pin, 29, upon the wheel, 28, arrives in contact with the lever, 19, thereby turning the stop-tap so as to open it and admit steam to the cylinders, 1, 2; when this is done the tappet, 11, will at the same time again arrive against the pins, 12, but on the side thereof opposite to that above mentioned, the levers, 13, will therefore be turned back into the position shown, thereby removing the pins, 14, from the excentric rods, 15, and allowing them to fall and again reverse the engine, so that the rakes will now be moved to the back of the furnace, and thus the operation continues. When the lever, 37, turns back after having shut off the steam, the spring joint of the lever, 19*, allows it to pass.

## CAST STEEL AND MALLEABLE IRON.

F. ELLERSHAUSEN, Ottawa, Canada.—Patent dated April 3rd, 1868.*

THIS invention relates to a peculiar process for manufacturing cast-steel and malleable iron direct from cast-iron, and to certain peculiar constructions and arrangements of apparatus to be employed for that purpose. The peculiar process whereby cast-iron is converted into cast-steel or malleable iron, consists essentially in the use of oxides of iron in a form possessing a considerable extent of surface, such, for example, as spongy iron as it comes from the puddling furnace, or sheet iron or iron curlings, somewhat similar to the beech shavings used in vinegar generators. This curled sheet iron is placed in a vessel or receptacle called the convertor, which is capable of being brought into communication with a furnace, in order to bring the sheet-iron curlings to a white heat, which temperature is maintained during a sufficient length of time to insure complete oxidation of the metal. When this is accomplished, the communication with the furnace is shut off, and a quantity of molten cast-iron is poured into the convertor, so as to unite with the oxide of iron. The great object in this process is to expose as large a surface as possible of oxide of iron to the fluid cast-iron, so as to effect a rapid and simultaneous combustion throughout the entire mass, which increases the temperature to such a degree as to cause the conversion to be completed whilst the metal is in a fluid state. Before the cast-iron is introduced into the convertor, decarbonising and purifying, or steel-improving agents, such, for example, as oxide of manganese, may be strewn or deposited in the interstices of the sheet-iron curlings, or its substitutes, in order to facilitate the combustion and purification. The subsidence of the combustion will indicate that the conversion is completed, when the metal may be run off and the process repeated.

According to one arrangement of apparatus for carrying out or applying the peculiar process hereinbefore described, a converting vessel or chamber is constructed upon the upper portion of a furnace, which may be of any convenient size and form, and be provided with blast-pipe and fire-bars. The convertor is divided from the furnace internally by an arched division, which forms the bottom of the convertor and the roof of the furnace. A series of flues or passages are made round the said division, communicating with the furnace, in order to allow of the curled iron, or its substitute, placed in the convertor, being thoroughly heated. Each flue or passage is capable of being closed, at pleasure, by a sliding stop of fire-clay or other suitable material, capped outside with metal, which stops are held in position, when closed, by means of holdfast screws, in order that they may not be forced out by the pressure of the molten metal in the convertor. Loose blocks or doors are provided for affording ready access to the interior of the flues or passages, and to the seats of the sliding stops, for repairs. The bottom of the convertor is hollowed or dished slightly, in order that, in the event of any of the metal in the act of oxidising becoming fluid, it may receive the same. A movable hood or cap is fitted on to the top of the convertor, of the same form and diameter at the base as the interior of the convertor, but tapering towards the mouth, which is curved to one side, and is in connection with a chimney shaft.

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* The Practical Mechanic's Journal, Nov. 1, 1868. *Ante*, p. 702.

According to another modification of apparatus, a removable cast-iron flue serves to convey the flame and heat from the furnace to the convertor, which convertor is supported on pillars or columns on the furnace roof; the said flue being placed over the aperture of the furnace when required for use, and removed again when not wanted. A flap-door or false bottom is hinged to the bottom of the convertor, and when this door is open the interior of the convertor is in immediate contact with the flame from the furnace, which is carried up through the circular removable flue. A lateral discharge aperture for the molten metal is formed at, or near, the bottom of the convertor, and upon the top of the convertor there is fitted, by hinges or otherwise, a cap or hood of the form above described.

In converting cast-iron into cast-steel by the aid of either of these apparatus, curled sheet iron is placed in the convertor; after which the hood is applied and connected with the chimney, and the sliding stops or removable flue are adjusted. Fire is then raised in the furnace beneath until the sheet iron curlings, or substitutes therefor, in the convertor are brought to a white heat, and so maintained till complete oxidation has taken place. The sliding stops are then closed, or the circular flue is removed, the door or flap (if used) is closed against the bottom of the convertor, and the top or hood is turned over. A sufficient quantity of molten cast-iron is then poured into the convertor to unite with the oxide of iron, causing rapid combustion throughout the mass and effecting conversion.

Fig. 139.

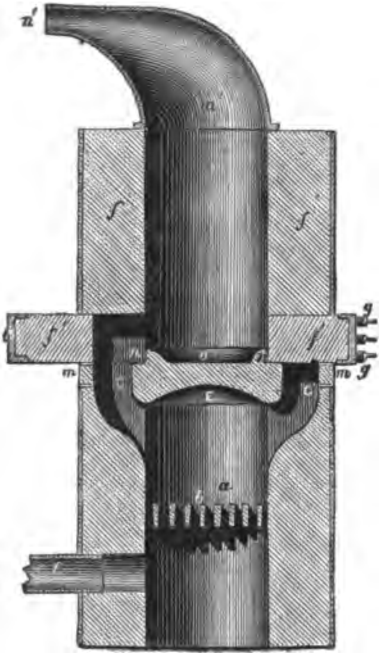


Fig. 139 of the engravings is a vertical section of one arrangement of the improved furnace and convertor, and

Fig. 140 is a plan of the convertor with the cap or hood removed. *a* is the furnace, *b* the fire-grate, *e* a fan-blast pipe underneath the fire-bars. The convertor, *f*, is placed directly over the furnace, *a*, as shown in Fig. 139, separated from it, however, by the arched roof, E. In order to heat the curled sheet-iron rolls which are placed in the interior of the convertor, four or more flues, C, C′, are arranged for the purpose of allowing the flame and heat to proceed from the furnace into the convertor, *f*. *f′ f′* are stoppers made of refractory material, and so arranged as to slide in and out, opening and closing the flues in doing so, as shown in Fig. 139, where the flue, C, is shown open, and the flue, C′, closed. These stoppers, *f′*, are provided with holdfast screws, *g*, *g*, to prevent any movement of the stoppers when the pressure of the liquid metal in the convertor is acting against them on the inside. In order to enable the operator to gain access to the flues, and also to repair any damage, with cement, in the corners, *n*, loose blocks, *m*, are so arranged as to afford access to that part; *a′ b′* are metal caps attached to the outer ends of the stoppers, *f′ f′*. The bottom of the convertor is curved or dished in the manner shown at *o*, so that in the event of any of the metal in the act of oxidising becoming fluid, it will be retained; *l* is the discharging spout for running off the molten converted metal; *m′* is a hood or cap-piece, more fully referred to on page 794, having an open contracted mouth at *n′*.

FIG. 140.

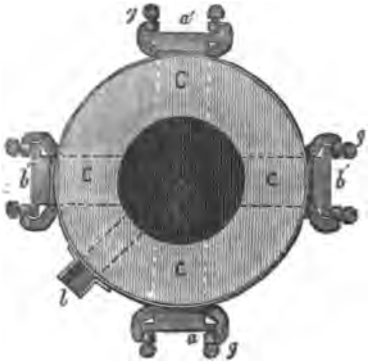
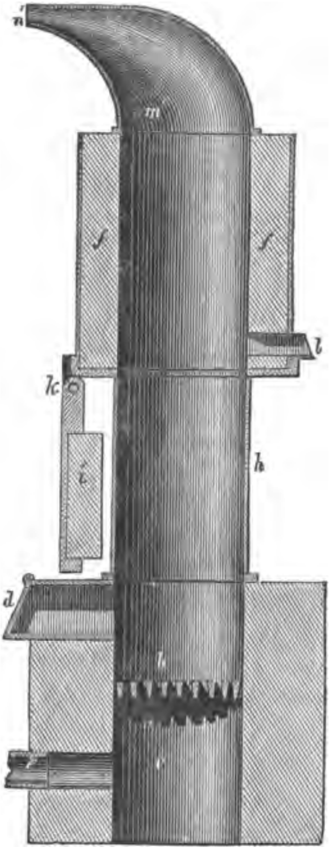


Fig. 141 is a vertical section of another modification of furnace and convertor. *a* is the furnace, of any convenient size or form, provided with fire-bars, *b*, *b*, ash-pit, *c*, feeding door, *d*, for the admission of fuel, and blast-pipe, *e*, of the usual form. On the top of this furnace is placed the convertor, *f*, constructed of brick, with an external boiler-plate casing to strengthen the same, as in the first modification; it may be supported on pillars, *g*′, *g*′, resting on the top of the furnace. *h* is a removable flue, for the purpose of conveying the flame or heat from the furnace to the convertor. This flue is circular in form, of cast-iron, and placed over

Fig. 141.



the aperture of the furnace when it is required to pass the flame or heat through the convertor. This flue is removed from under the convertor when it is required to close the flap-door or false bottom, *i*, attached to the lower side of the convertor by the hinge, *k*; this door is also lined on the inside with fire-brick. When this door is open, the whole interior area of the convertor is in immediate contact with the flame from the furnace carried through the flue, *h*, which is then in place for that purpose. *l* is an aperture for the discharge of the molten metal from the convertor, when the same is ready for withdrawal; *m'* is the hood or cap-piece of metal, of the peculiar form shown in the drawings, circular at the base, and of the same internal diameter as that of the convertor; it is attached to the top of the convertor by a hinge or other suitable fastening, so arranged as to permit of its being elevated or turned back when required. This cap-piece terminates in a reduced diameter at *n'*, for the purpose of connection with a chimney shaft to carry off the products of combustion.

On the principle that carbon cannot exist at a white heat in the presence of oxygen without combustion ensuing, and also that the combustion will proceed with a rapidity dependent on the extent of surface exposed to the united action of the carbon and oxygen with an increase of temperature, the invention or discovery has been made that, by the use of certain mechanical appliances in conjunction with the foregoing, cast-iron may be readily converted into cast-steel or into malleable iron, and which may be accomplished in the following manner, with greater economy both in time and expense, and at the same time yielding a superior description of steel or malleable iron.

These results are brought about in the following manner:—Sheet-iron is curled in a similar manner to the beech shavings used in vinegar generators, and is placed in the interior of the converter, *f*; this vessel is open at the top, but is provided with means for the upward passage of the flame from the furnace, *a*, through the interior of the converter; the cover, *m'*, is then put in place and connected with the chimney, the flues or passages, c, c, the lower door, *i*, are opened, and the flue, *h*, in the latter arrangement put in place. Fire is then introduced into the furnace, *a*, and the temperature raised to such a degree as to bring the sheet-iron curlings in the converter to a white heat, and continued for a sufficient length of time to insure the complete oxidation of the same. When this is accomplished, the flue, *h* (if employed) is removed, and the door, *i*, closed, and the top cover, *m'*, is turned over, or the stops, *f'*, *f'*, in the first arrangement, are pushed in, so as to close the passages, c, c. A sufficient quantity of molten cast-iron is then poured into the top of the converter, to unite with the oxide of iron as may be required. It will be evident from the manner in which the sheet-iron curlings, afterwards converted into an oxide of iron, were originally placed in the converter, that a large surface of oxide of iron is exposed, within a comparatively small space, to contact with the incoming molten cast-iron, uniting the particles of each in close conjunction, and causing a rapid combustion throughout the entire mass, which increases the temperature to such a degree as to effect the conversion while the metal is in a fluid state. In place of the sheet-iron curlings other oxides may be used, if they possess the desired extent of surface—for instance, spongy iron as it comes from the puddling furnace.

In either of the above cases before the cast-iron is introduced into the converter, decarbonising and purifying, or steel improving agents, such, for instance, as oxide of manganese, may be strewn or deposited in the interstices of the sheet-iron curlings, or its substitutes, in order to facilitate the combustion and purification. When the conversion is completed, which can be easily determined by the subsidence of the combustion, the metal is drawn off through the tap or discharge spout, *l*, and the process is repeated. The quantity of metal to be operated on during each conversion may range from ½ of a ton to 10 tons.

## SIEMENS'S PROCESS OF PRODUCING STEEL DIRECT FROM THE ORE.

THE experiments on this important process are now so far completed, that it is expected the process will soon be introduced into practice.

Mr. Siemens described the process in a lecture delivered before the Fellows of the Chemical Society on the 7th of May, 1868, in the following terms:—

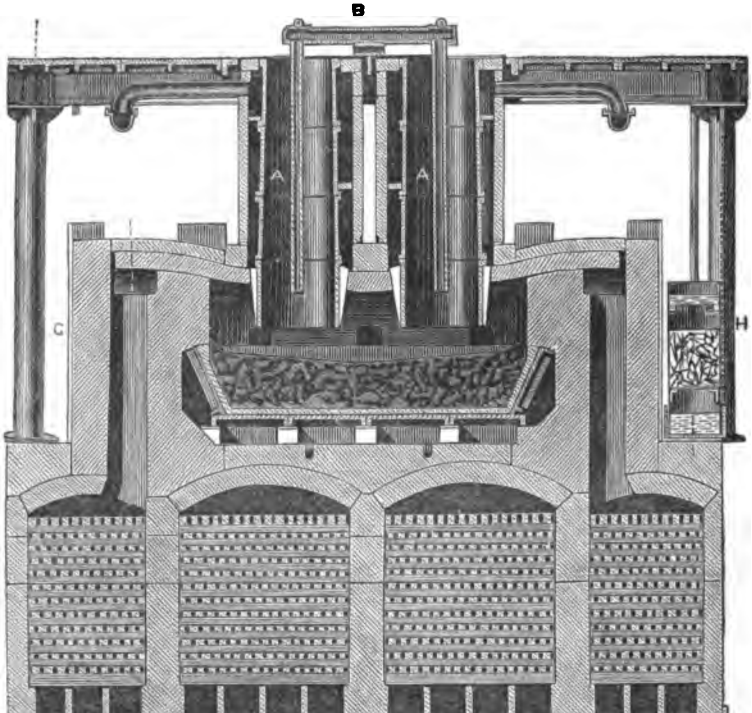
Although I have succeeded in producing malleable steel from ordinary English iron by this process, it would be unreasonable to expect steel of really high quality, in using those materials which are already contaminated in the blast-furnace; and I am sanguine in the expectation of producing cast-steel superior in quality, and at a low cost, directly from the better description of ores, such as the hæmatites, magnetic oxides, and the spathic carbonates. My experiments in this direction extend over several years; and in 1867 I sent a few bars of steel produced from hæmatite ore, to the French Exhibition, which had stood a high test in Kirkaldy's machine. A "grand prix" was awarded for this and other applications of the regenerative gas furnaces.

Having tried various modifications of the furnace, I have arrived at a form of apparatus not dissimilar to the one shown in Figs. 142, 143, 144, and 145. The furnace and tapping arrangements are, indeed, the same as those used in the Siemens-Martin steel process, except that for the slanting hoppers, vertical hoppers over the middle of the bath are substituted, in which the ore gradually descends. Each hopper is formed of a cast-iron pipe, supporting a clay-pipe, which is attached to it by means of a bayonet joint, and reaches down into the furnace, while the cast-iron pipe rests with its flange on the charging platform.

A fire space is provided surrounding each hopper, through which flame ascends from the furnace, and is allowed to escape in regulated quantities near the upper extremity of the retort, the object being to heat the latter and the ore contained in it to a red heat. A wrought-iron pipe descends into each hopper from a general gas tube above, through which a current of ordinary producer gas is forced in amongst the heated ore. The propulsion of the gas is effected most conveniently by means of a steam jet in the gas tube leading from the main gas channel to the top of the furnace, care being taken to effect a total condensation of the steam by passing the gas finally through a small scrubber, in which water trickles over pieces of coke. In this way the gas is at the same time purified from sulphurous acid, the sulphur of which might otherwise combine with the reduced ore.

FIG. 142.

THE REGENERATIVE GAS FURNACE AS APPLIED TO THE PRODUCTION OF CAST-STEEL DIRECTLY FROM THE ORE.



Longitudinal Section on the Line G H.

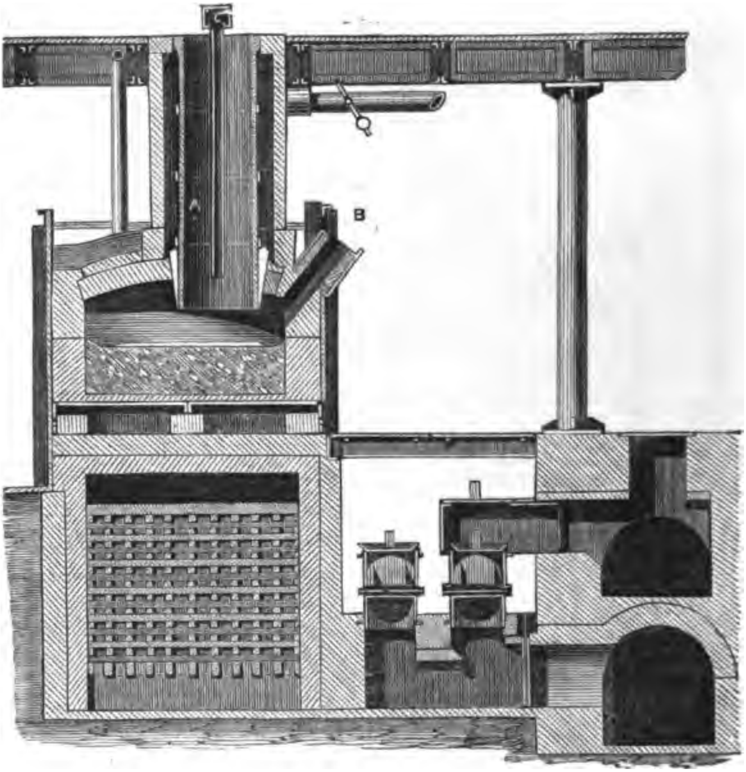
The furnace is charged in the following manner :—

The hoppers and gas pipes being placed in position, about $\frac{1}{4}$ cwt. of charcoal is charged through each hopper to form a basis for the ore with which these are afterwards filled.

About 10 cwts. of pig metal is charged through the ports at the back or front of the furnace, which, upon being melted, forms a metallic bath below the hopper. In the meantime, the ore in the lower parts of the hoppers, being heated in an atmosphere of reducing gas, has become partially reduced into metal sponge, which, in reaching the metallic bath, is readily dissolved in it, making room for the descent of the superincumbent ore, which is likewise reduced in its descent and dissolved in due course, fresh ore being continually supplied on the charging platform. The dissolution of the reduced ore proceeds with extraordinary rapidity, but is practically limited by the time necessary to

FIG. 143.

THE REGENERATIVE GAS FURNACE AS APPLIED TO THE PRODUCTION OF CAST-STEEL DIRECTLY FROM THE ORE.

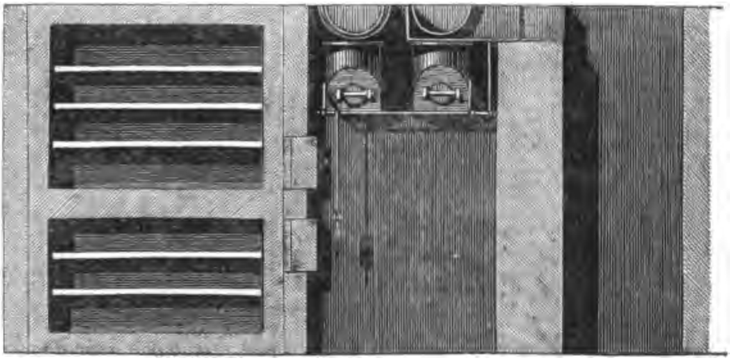


Transverse Section on Line C D.

effect the reduction of the ore in the hopper, which occupies several hours. It is, however, not essential that the ore should be thoroughly reduced before reaching the bath, because the carbon contained in the cast metal serves also to complete the operation.

I prefer to employ a mixture of hæmatite and spathic ore, containing the elements for forming a fusible slag, which will accumulate on the surface of the metallic bath, and may be from time to time removed through the centre door. If the ore contains any silica, it is necessary to add some lime or other fluxing materials, but it is desirable to employ ores containing little gangue, in order not to encumber the furnace with slag, reserving the poorer ores for the blast furnace. The ore should, moreover, be in pieces ranging from the size of a pea to that of a walnut, in order to be pervious to the reducing gases. If ores in the form of powder are employed, it is necessary to mix them with about 10 per cent by weight of light carbonaceous materials, such as dry peat, wood, or charcoal.

FIG. 144.



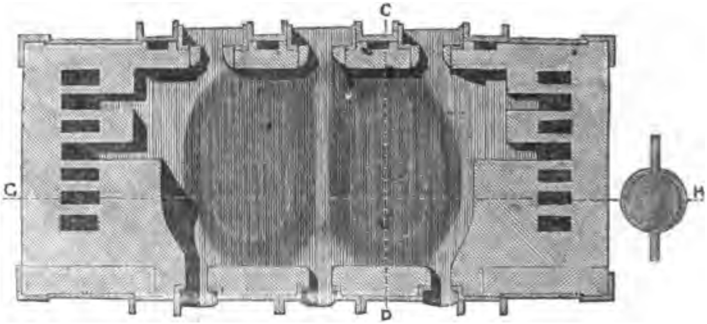
Half plan through the regenerator chamber and main gas flue.
Scale ¼ inch to a foot.

A, A, Charging shoots for the ore.
B, B, Charging shoots for the pig-iron.
C, Tube conveying reducing gas into the mass of ore.

The metallic bath having sufficiently increased in the course of from three to four hours, the supply of ore is stopped, and that contained in the hoppers is allowed to sink. Before the hoppers are empty, a false cover of cast-iron, lined with clay at its under side, is introduced, being suspended from above by a strong wire, in order to prevent the access of flame to the interior of the empty hoppers. Charcoal and ore are filled in upon the top of this false cover, and, on cutting the wire, afterwards form the commencement of the succeeding charge.

When all the ore has disappeared, the metallic bath is tested as before described in reference to the melting of scrap. If it should be partially solidified, cast-iron is added to re-establish complete liquefaction; but if, on the other hand, the bath contains an excess of carbon, oxidising agents may be added as before described, in requisite proportion.

FIG. 145.



Section of plan through the melting chamber. Scale ¼ inch to a foot.

From 5 to 8 per cent of spiegeleisen is then added, and the furnace is tapped.

The quality of the steel produced is chiefly dependent upon the quality of the ore, but considering that ores of great freedom from sulphur, phosphorus, or arsenic can be had in large quantities, this process contains all the elements for producing steel of high quality.

Having tried a variety of ores, I do not attach much importance to their precise composition, so long as they are comparatively free from gangue, and from sulphur and phosphorus, the heat being sufficient to reduce the most refractory. My experience is, however, as yet limited to experimental working.

I hoped to have been in a position to have given the temperature of this furnace, as determined by an electric resistance pyrometer, which I have constructed for this purpose, but have not yet been able to obtain satisfactory results, owing to the destruction of the coil of platinum wire, which has to be exposed to the heat. My efforts were baffled, moreover, by the fact, interesting in itself, that platinum wire produced by fusion in Deville's furnace does not increase in electrical resistance with increase of temperature, in the same ratio as that produced by the old process, owing probably to the presence of carbon or other alloy in fractional quantities.

Avoiding the use of fused platinum wire, I have measured temperatures by electrical resistance up to a full welding heat, which I estimated at 1600° C. = 2900° F.; and in judging the heat of the steel melting furnace by comparison of effects, I should put it at not less than 2200° C. = 4000° F. The effect of this degree of heat may be judged by the following:—

An ingot of rather hard cast-steel, weighing 6 cwts., was introduced into the furnace to be incorporated with the bath of steel. The ingot was nearly cold, and was allowed to remain fifteen minutes upon the bank before it was pushed into the bath, where it was completely dissolved in fifteen minutes, the time occupied in heating and melting the ingot being thirty minutes. A cube of wrought metal of nearly 8 inches, weighing 130 lbs., was also introduced cold into the furnace, and allowed to remain upon the bank during ten minutes to be heated externally to whiteness, before being pushed into the metallic bath, when twelve minutes sufficed to render it completely liquid. It must be borne in mind that these results are produced without a strong draught, the flame being, indeed, so mild as not to oxidise the unprotected metal, which can be maintained for several hours as liquid steel in the furnace without adding carbon in any form.

It may be a matter for surprise that the material composing the furnace can be made to resist such a heat, and it must be admitted that best Dinas brick is the only brick capable of resisting for four to five weeks, by which time the thickness of the arch is reduced to about 2 inches, by the absolute fusion of the inner surface; but this excessive heat is confined to the heated chamber only, the regenerators being at such a moderated heat, that the chequerwork will stand for months, and the arches for years of constant working.

## SIEMENS'S REGENERATIVE FURNACES.

THE following statements concerning these furnaces appear in an interesting paper read by Mr. Josiah T. Smith, before the Iron and Steel Institute at Middlesborough, in September last:—

The temperature of the gas at the junction of the upcasts with the tubes was from 1250° to 1300° F., a rather higher point than had yet been noticed. Before it had travelled 200 feet in the tube, with an external atmosphere at 60°, the temperature was reduced to about 130°. The author had been unable to ascertain the exact quantity of heat lost by radiation in the interval, but the experiments, although not complete, were sufficient to show that the quantity was so small that at present he could see no way of economically applying it. This lowering of the temperature and condensation of the gases was of advantage in many respects. The gas being heavier, caused, in its transit through the tubes and the various downcasts, a syphon action; and thus not only drew the gas from the producers to the furnaces, but, by keeping up a slight outward pressure, prevented the admission of air through any crevice in the tubes or the expansion boxes. It also deposited the tar from the coals into a series of wells beneath; while the water in the fuel was also condensed, and thus prevented from causing a waste of metal by introducing a too great supply of oxygen into the furnaces. For many months each producer at

Barrow had volatilised 3 tons of coal per twenty-four hours, and the greatest economy effected was when the consumption had not exceeded 50 cwts. Estimating the weight of 1 cubic foot of gas at the ordinary temperature of the air to be 0·075 lbs., the volume of carbonic oxide, hydrocarbon, and hydrogen, from 1 ton of coal would be about 53,000 feet; and the volume of nitrogen about 122,000 feet, or making together a total of 175,943 feet. The consumption of coal in the producers at Barrow being 500 tons per week, it gave an amount of gas passing through the tubes at the rate of 6½ feet per second, of 87,000,000 cubic feet; or through the various furnaces, adding the quantity of air there admitted, of 6600 tons. The saving of fuel by this process at Barrow was, over a period of two years, no less than 44 per cent; but the actual money saving, by the use of a particular kind of coal, had been more than one-half. The yield of the gas furnaces, taken over the same period, showed a saving of 31 per cent as compared with the work at the firing furnaces, and the amount of repairs was just two-thirds of the old cost. In these three particulars was undoubtedly to be found the chief economy; but the adoption of the system enabled them to preserve greater cleanliness and order in their works, and an entire absence of smoke met a difficulty which in the neighbourhood of large towns, was every year becoming a greater grievance. There was, he admitted, a slightly increased outlay on the plant; but taking into consideration the increased capabilities as to quantity, it would be found to represent the difference in cost between the two systems.

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Long experience has furthermore proved that in Siemens's furnaces 1 ton of pig-iron, No. 3, and 1 cwt. of spiegeleisen produce 1 ton of mild steel. 15 cwts. of coal (small slack) are consumed per ton of steel ingots, and 5 cwts. more for converting the ingots into steel rails or plates.

In puddling, 10 cwts. of small coal are used per ton of iron, and the yield of iron is within 1 or 2 per cent of the pig-iron charged.

# WEIGHTS AN

## O

## DIFFERENT

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### Aust

1 foot = 0·31611 metre.
1 cubic foot = 0·03159 cubic m
1 cwt. (Wiener centner) = 100
1 lb. = 32 loth = 560·012 gran
1 lb. (Münzpfund) = 0·5 kilo.

### Bade

1 foot = 10 inches (1 inch = 1
= 0·3 metre.
1 cubic foot = 0·0270 cubic me
1 centner = 100 lbs. (1 lb. = 3
1 lb. = 100 centass = 1000 dek

### Bavar

1 foot = 12 inches (1 inch = 12
1 cubic foot = 0·0249 cubic met
1 centner = 100 lbs. (1 lb. = 32
1 lb. = 0·56 kilo.

**Belgium.** (As

### England.

1 foot = 12 inches = 0·3048 metre.
1 cubic foot = 0·0283 cubic metre.
1 yard = 3 feet = ½ fathom = 0·9144 metre.
1 cubic yard = 0·764 cubic metre.
1 cwt. avoirdupois = 112 lbs. (1 lb. = 16 ounces; 1 ounce = 16 drachms; 1 drachm = 27·344 grains) = 50·8 kilos.
1 lb. avoirdupois = 0·4536 kilos.
1 cwt. troy = 100 lbs. (1 lb. = 12 ounces; 1 ounce = 12 pennyweights; 1 pennyweight = 24 grains) = 37·325 kilos.
1 lb. troy = 0·37325 kilos.
1 ton = 20 cwts. avoirdupois = 1015 kilos.
1 fodder = 21 cwts. avoirdupois.

### France.

1 metre = 10 decimetres = 100 centimetres = 1000 millimetres = 0·1 dekametre = 0·01 hektometre = 0·001 kilometre = 3·2809 English feet.
1 cubic metre = 1 kilolitre = 1 stère (measurement for coal and fire-wood) = 35·317 English cubic feet = 22·0097 English gallons.
1 litre = 1 cubic decimetre.
1 corde (wood) = 4·387 stères.
1 kilogramme = 1000 grammes = 2·2046 lbs. avoirdupois (English).
1 metric cwt. = 100 kilos. = 1·9584 English cwts. avoirdupois.
1 ton = 1000 kilos. = 0·985 English ton.
1 lb. = 500 grammes = 16 onces = 128 gros = 9216 grains.

### North America (United States.)

(As in England).

### Norway.

1 foot = 12 inches (1 inch = 12 lines) = 0·3139 metre.
1 cubic foot = 0·0309 cubic metre.

1 load = 16¼ ship pounds = 2596·36 kilos.
1 ship pound = 20 lies-pound.
1 lies-pound = 16 lbs. = 159·78 kilos.
1 cwt. = 49·93 kilos.
1 lb. = 500 grammes.

## Prussia.

1 foot = 12 inches = 0·3139 metre.
1 cubic foot = 0·0309 cubic metre.
1 cwt. (centner) = 100 lbs. = 50 kilos. = 0·9842 English cwt.
1 lb. = 30 loth = ½ kilogramme.
1 loth = 10 quentchen = 100 cents = 1000 korn.

## Russia.

1 foot = 1 English foot.
1 archina = 4 tschetwert = 16 werschock = 25 English inches.
1 pud = 40 lbs. = 16·38 kilos.
1 lb. = 32 loth = 0·4095 kilo.
1 loth = 3 solotnik.
1 solotnik = 96 doli.

## Saxony.

1 foot = 12 inches = 0·2832 metre.
1 cubic foot = 0·0227 cubic metre. Weights as in Prussia.

## Sweden.

1 foot = 10 inches (1 inch = 10 lines) = 0·296901 metre,
1 lb. (schiffspfund) = 20 liespfunde = 170 kilos.
1 lb. (liespfund) = 20 skalpfund.
1 lb. (skalpfund) = 32 loth = 100 ort = 1000 korn = 424·665 grammes.
1 loth = 13·27 grammes.
1 cwt. (centner) = 120 lbs. = 51·04 kilos.
1 lb. (schiffspfund) for weighing pig-iron = 26 liespfund = 195·25 kilos.
1 skalpfund = 375·404 grammes.

## Spain.

1 vara castillane = 3 teroias (feet) = 4 palmes = 36 pouces = 48 doigts = 432 lignes = 5184 points = 0·8359 metre.

1 foot = 0·278635 metre.

1 quintal cast = 4 arobes = 46·01 kilos.

1 arobe = 25 livres.

1 livre = 2 marcs = 16 onces = 128 oitavas = 256 adarmes = 768 tornines = 9216 grains = 1·1502 kilos.

1 onzi = 28·29 grammes; 1 fanega = 0·565 hectolitre.

## Table for Comparing Measures.

### *a. Feet.*

| Prussia. | Austria. | Saxony. | Switzerland. | England and Russia. | France. | Metre. |
|---|---|---|---|---|---|---|
| 1 | 0·9929 | 1·1083 | 1·0462 | 1·0297 | 0·9662 | 0·3138 |
| 1·0072 | 1 | 1·1163 | 1·0537 | 1·0371 | 0·9731 | 0·3161 |
| 0·9023 | 0·8959 | 1 | 0·9440 | 0·9291 | 0·8718 | 0·2832 |
| 0·9307 | 0·9240 | 1·0314 | 0·9736 | 0·9583 | 0·8992 | 0·2921 |
| 0·9559 | 0·9490 | 1·0594 | 1 | 0·9843 | 0·9235 | 0·3000 |
| 0·9711 | 0·9642 | 1·0763 | 1·0160 | 1 | 0·9383 | 0·3048 |
| 1·0350 | 1·0276 | 1·1471 | 1·0828 | 1·0658 | 1 | 0·3248 |
| 3·1862 | 3·1634 | 3·5312 | 3·3333 | 3·2809 | 3·0784 | 1 |

### *b. Square Feet.*

| Prussia. | Austria. | Saxony. | Switzerland. | England and Russia. | France. | Metre. |
|---|---|---|---|---|---|---|
| 1 | 0·9858 | 1·2283 | 1·0945 | 1·0603 | 0·9335 | 0·0985 |
| 1·0144 | 1 | 1·2460 | 1·1103 | 1·0756 | 0·9470 | 0·0999 |
| 0·8141 | 0·8026 | 1 | 0·8911 | 0·8633 | 0·7600 | 0·0802 |
| 0·8661 | 0·8538 | 1·0639 | 0·9480 | 0·9184 | 0·8086 | 0·0853 |
| 0·9137 | 0·9007 | 1·1222 | 1 | 0·9688 | 0·8529 | 0·0900 |
| 0·9431 | 0·9297 | 1·1584 | 1·0322 | 1 | 0·8804 | 0·0929 |
| 1·0712 | 1·0560 | 1·3158 | 1·1725 | 1·1359 | 1 | 0·1055 |
| 10·1519 | 10·0074 | 12·4694 | 11·1111 | 10·7643 | 9·4768 | 1 |

### *c. Cubic Feet.*

| Prussia. | Austria. | Saxony. | Switzerland. | England and Russia. | France. | Metre. |
|---|---|---|---|---|---|---|
| 1 | 0·9787 | 1·3613 | 1·1450 | 1·0918 | 0·9019 | 0·0309 |
| 1·0217 | 1 | 1·3909 | 1·1699 | 1·1156 | 0·9215 | 0·0316 |
| 0·7346 | 0·7190 | 1 | 0·8411 | 0·8021 | 0·6626 | 0·0227 |
| 0·8061 | 0·7890 | 1·0973 | 0·9230 | 0·8801 | 0·7271 | 0·0249 |
| 0·8733 | 0·8548 | 1·1889 | 1 | 0·9535 | 0·7877 | 0·0270 |
| 0·9159 | 0·8964 | 1·2468 | 1·0487 | 1 | 0·8261 | 0·0283 |
| 1·1087 | 1·0851 | 1·5093 | 1·2695 | 1·2106 | 1 | 0·0343 |
| 32·3459 | 31.6571 | 44·0318 | 37·0370 | 35·3166 | 29·1738 | 1 |

## TABLE FOR COMP.

| Prussia.<br>lbs. | Austria.<br>lbs. | Sweden.<br>lbs. |
|---|---|---|
| 1 | 0·8929 | 1·1755 |
| 0·9354 | 0·8352 | 1·0996 |
| 1·1200 | 1 | 1·3166 |
| 0·8507 | 0·7595 | 1 |
| 0·9072 | 0·8100 | 1·0664 |
| 0·8190 | 0·7313 | 0·9628 |
| 2·0000 | 1·7857 | 2·3511 |

# GLOSSARY OF TECHNICAL TERMS, &c.

WITH REFERENCES TO VOLUME AND PAGE WHERE THEIR EXPLANATIONS MAY BE FOUND.

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| | VOL. | PAGE. |
|---|---|---|
| **Abdarr Process.** A process for desilverising argentiferous copper ores | i. | 246 |
| **Abstrich** (German). A scum formed upon the surface of the metallic bath in melting lead in the cupelling process for extracting silver | i. | 279 |
| **Abzug** (German). A covering consisting of the less fusible substances formed upon the surface of the metallic bath in melting lead | i. | 279 |
| **Adapters.** Used in the Belgian-Silesian system of extracting zinc | i. | 449 |
| **Aludels.** Clay tubes formerly employed as condensers or receivers in the extraction of mercury from its ores | i. | 505 |
| **Amalgamation Process.** A process for the extraction of silver, &c., by means of mercury | i. | 317 |
| **American Hearth Process.** A process for the extraction of lead | i. | 72 |
| **Andreaskreuz.** A cross channel in the foundation of Belgian blast furnaces | ii. | 434 |

| | VOL. | PAGE. |
|---|---|---|
| Feathered Shot Copper. Copper granulated by pouring the fused metal into cold water | ii. | 182 |
| Feeding | ii. | 546 |
| Feeding Head | ii. | 633 |
| Ferruginous Bears. Iron deposits in the furnace hearth in the raw smelting of copper ores | ii. | 44 |
| Fine Metal | ii. | 133 |
| Finery Fires | ii. | 740 |
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